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Date: 9/3/80

Project Title: Nuclear Chemistry Research & Spectroscopy with Radioactive Sources

Project No: G-33-659

Project Director: Dr. R. W. Fink

Sponsor: Department of Energy; Oak Ridge Operations

Agreement Period: From 2/1/80 Until ~~1/31/81~~ 1/31/82

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Sponsor Contact Person (s):

Technical Matters

Contractual Matters (thru OCA)

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NOTE: Follow-on project to G-33-645 (Mod. A015)

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Assigned to: Chemistry (School/~~Laboratory~~)

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Date 6/2/83

Project Title: Nuclear Chemistry Research and Spectroscopy with Radioactive Sources

Project No: G-33-659

Project Director: Dr. R. W. Fink

Sponsor: DOE/Washington and Oak Ridge

Effective Termination Date: 1/31/82

Clearance of Accounting Charges: 1/31/82

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- [ ] Final Invoice and Closing Documents
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- [ ] Final Report of Inventions
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Continued by Project G-33-615

Pink sheet issued to close project at same time as G-33-615 is closed. File indicates patent statements and accounting for property activities completed by 10/25/82.

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NUCLEAR CHEMISTRY RESEARCH AND SPECTROSCOPY WITH RADIOACTIVE SOURCES

Sixteenth Annual Progress Report

U. S. Department of Energy

Contract DE–AS05–76ERO–3346

R. W. Fink

Professor of Chemistry & Principal Investigator

October 31, 1980

GEORGIA INSTITUTE OF TECHNOLOGY

SCHOOL OF CHEMISTRY

ATLANTA, GEORGIA 30332

1980

Tel. (404) 894–4030

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1.0 INTRODUCTION

Owing to the extended shutdown of UNISOR to install an on-line laser spectroscopy system and to shutdowns of the Oak Ridge Isochronous Cyclotron for modification to accept heavy ion injection from the 25 MV folded tandem accelerator (HHIRF), our first UNISOR runs in more than 16 months did not begin until late July, 1980. Therefore, we used this period of time to reduce almost completely the large backlog of unanalyzed UNISOR data accumulated from previous runs; in particular, our investigations of the A = 201 mass chain (5 runs) and of ^{187}Au decay were carried out.

Our goal remains to establish the detailed nuclear spectroscopy (including the weak γ-ray transitions and conversion electrons) of nuclei in regions near the Z = 82 closed shell. Such completeness in the spectroscopic measurements is essential in determining the systematic trends which underlie the interpretation of nuclear structure far from stability. In view of this requirement, our July, 1980, run [^{181}Ta(^{12}C, 6n)^{187}Au] to study the γ-rays in the decay of 8.4 min ^{187}Au produced data of the best statistical quality ever obtained at UNISOR.

Considerable progress has been made this year in the systematic investigation of the Interacting Boson-Fermion Approximation (IBFA) predictions for odd-A gold isotopes (A = 185-197) and their comparison with current experimental results. The latest version of the computer codes PHINT and ODDA has supplanted the earlier one on the CDC Cyber 70/74 Georgia Tech computer. In addition, the IBFA code NPBOS was implemented this year on the Georgia Tech computer.

Our completed investigation of the highly retarded M4 transitions from the $s_{1/2}$ intruder isomeric states in ^{199,201}Bi, on which a manuscript will shortly appear in <u>Nuclear Physics A</u>, was cited by the visiting UNISOR review committee as one of the major achievements in UNISOR research in the past year.

On campus, the three-parameter XX·t, Xce−·t, and Xγ·t x-ray coincidence measurements implemented on our ND-4420 multiparameter, multichannel analyzer are similar to coincidence measurements at UNISOR and provide excellent training for our graduate students and postdoctoral investigators who will then later participate in UNISOR research. Moreover, such coincidence measurements provide experience in handling the more difficult electronic timing problems inherent in low-energy photon and electron spectroscopy which is becoming exceedingly important at UNISOR.

These XX·t three-parameter measurements with high resolution Si(Li) and Ge(HP) x-ray detectors are used to obtain the L_1-subshell yields ω_1, f_{12}, and f_{13} and L_2-subshell Coster-Kronig transition probability f_{23}. The experimental data on L_1-subshell yields are sparse because of the lack of suitable radioactive sources that produce L_1 atomic vacancy states. There is a need to collect reliable experimental information for comparison with the theory. In the case of f_{23}, the most recent relativistic calculations indicate that our current experimental values agree well with the theoretical estimates. Recent advances in the analysis of the coincidence spectra to measure these yields are effectively employed to complete a comprehensive set of measurements on Z = 82, in order to obtain all the parameters of interest , ie, the fluorescence yields ω_i, the Coster-Kronig yields f_{ij}, and the radiative branching ratios s_i.

2.0 Nuclear Spectroscopy Studies

2.1 Decay of ^{201}Po and ^{201}At Isobars

An analysis of the decay of ^{201m,g}Po (9 min, 14 min) is nearing completion under the coordination of Dr. R. A. Braga. The activity was produced at UNISOR by bombarding natural Ir with 113 MeV ^{14}N ions, and the data acquired includes γ-ray and ce$^-$ singles, γγ·t coincidence, and γ-ray and ce$^-$ multispectral data. Prior to our study the most comprehensive investigation of the excited states in ^{201}Bi was that of Korman, et. al.[1).]

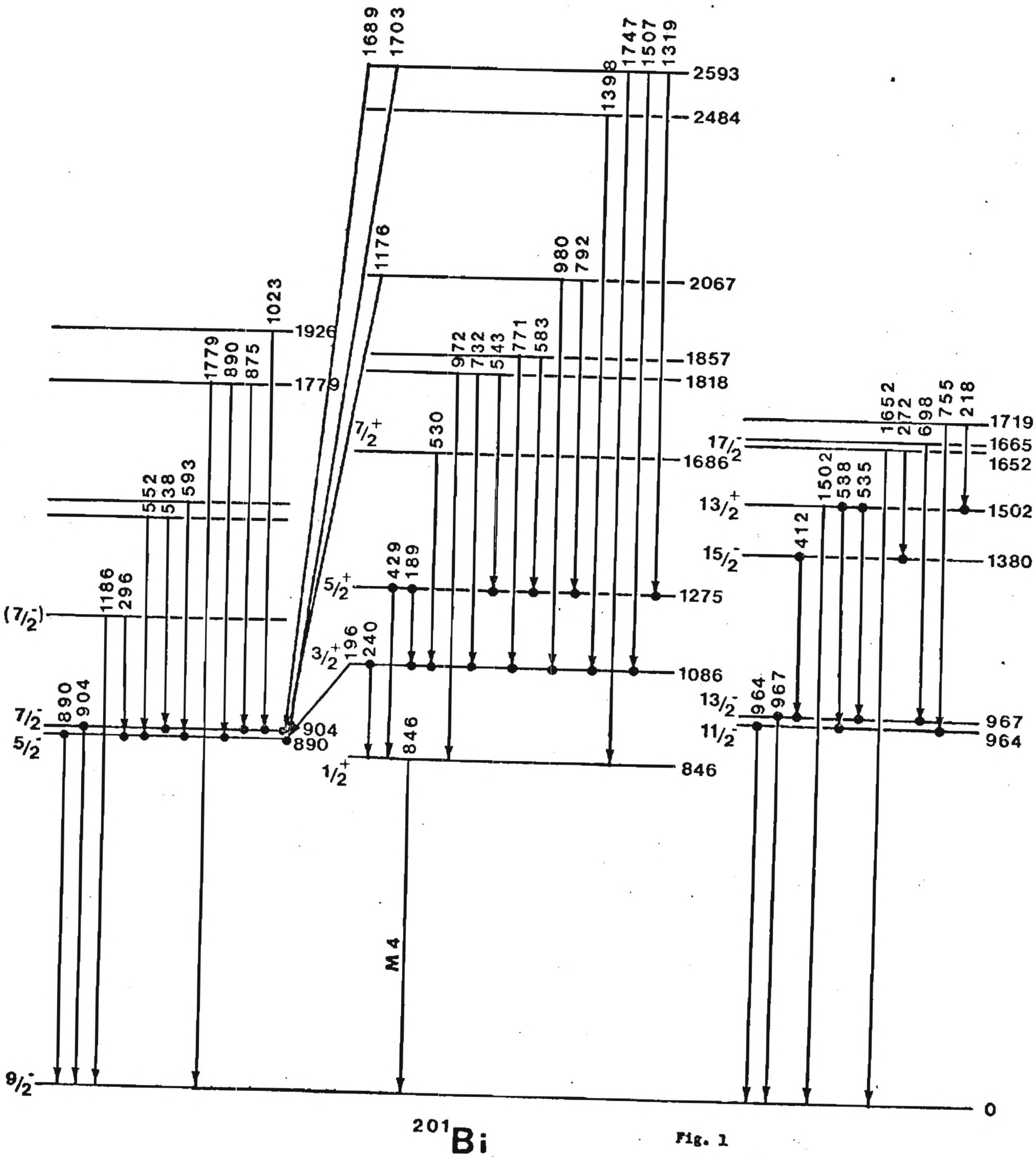
---

[1] A. Korman, D. Chlebowska, T. Kempisty, and S. Chojnacki, Acta Phys. Polon. (Warsaw) B7, 141 (1976)

In Table I we list the γ-rays assigned to transitions in ^{201}Bi, along with their intensities and tentative multipolarities, and Table II is a listing of observed coincidence relationships. From these data, we construct the decay scheme shown in Fig. 1. (A number of weak, unassigned γ-rays observed in the spectra are not listed in the tables nor shown in Fig. 1.) A major portion of this scheme is the band built upon the $s_{1/2}$ shell-model intruder state and the M4 isomeric transition depopulating this state in ^{201}Bi, (see Sect. 2.2). In addition we observe a level structure populated by the decay of the high-spin 13/2+ isomeric state of ^{201m}Po (9 min),(shown in Fig. 1, right side), as well as a structure fed by the decay of the 3/2- ground-state of ^{201g}Po (14 min) (shown in Fig. 1, left side). We observe both ^{201}Po isomers, since the high spin upper state, produced almost exclusively in the heavy ion reaction, feeds the lower spin ground-state via an isomeric cascade.

This work is part of a UNISOR effort to investigate the systematics of the light Z = 83 nuclei. It is of particular interest to study the coupling of the single-particle, or hole states to the even-even Pb or Po cores. In this description, the 5/2-, 7/2- and the 11/2-, 13/2-, 15/2-

Fig. 1 - Partial decay scheme of ^{201}Bi populated in the decay of ^{201m,g}Po (9 min, 14 min). Relative intensities appear in Table I, along with tentative multipolarity assignments. The right side of the decay scheme is populated from the decay of the 13/2+, 9 min ^{201m}Po isomer, while the left-side arises from decay of the 3/2-, 14 min ^{201g}Po ground state.



1689
1703
1747
1507
1319
2593
1398
2484
1176
980
792
2067
1023
1926
1779
890
875
972
732
543
771
583
1857
1818
1779
1652
272
698
755
218
1719
7/2+
530
17/2-
1665
1686
1652
552
538
593
1502
538
535
13/2+
1502
412
15/2-
1380
1186
296
429
189
5/2+
1275
(7/2-)
3/2+
196
240
1086
890
904
13/2-
964
967
967
7/2-
904
890
11/2-
964
5/2-
846
1/2+
846
M4
9/2-
0

^{201}Bi

Fig. 1

state in ^{201}Bi result from the coupling of the $h_{9/2}$ single proton state to the 2+ one-phonon and 4+ two-phonon states of the ^{200}Pb core. The resulting coupling scheme can also be compared to the Z = 81 proton-hole system ($\pi h_{9/2}^{-1} \otimes {}^{200}Pb \rightarrow {}^{199}Tl$). Upon completion of this study, publication is planned in Nuclear Physics A.

Also this year we have continued our investigation of the decay of ^{201}At. This is part of an effort to obtain information on excited states of Po isotopes. These comprise part of a region which forms a completely new family of transitional nuclei and provide tests for models and concepts that have been developed to describe nuclei with $Z \leqslant 80$. In particular, excited states of the odd-mass Po isotopes, and especially the low-spin states due to the coupling of the $i_{13/2}$ unpaired neutron to the core, would reveal the shapes of the nuclei, the location of the Fermi energy, and the validity of the Meyer ter Vehn triaxial rotor model in this region.

Since ^{201}At decays via an alpha branch as well as by β^+/EC decay, some information on levels in ^{197}Bi as well as its decay is expected. Activities of ^{201}At were produced via the $^{nat}Ir(^{16}O,6n)$ reaction at UNISOR. The data acquired so far consist solely of γ-ray multispectral singles. The analysis of these data has resulted in the identification of several γ-rays associated with the ^{201}At decay. The γ-rays observed at 494, 763, and 849 keV decay with halflives ranging from 1.2 to 1.7 min, consistent with the previously-reported halflife of 1.5 min reported for ^{201}At[2], while several others decay with a halflife consistent with ^{197}Bi decay (6.4 min)[3] (10 min[4]). We note that the decay curves we obtain for

[2] P. Hornshøj, P. G. Hansen, B. Jonson, Nuclear Phys. A230, 380 (1974)
[3] M.S. Rapaport, in Ann. Prog, Rept. ORO-3346-173 (edited by R.W. Fink); p. 22 (1975)
[4] Y. LeBeyec, M. Lefort, J. Livet, N.T. Porile, and A. Siivola, Phys. Rev. C9, 1091 (1974)

the γ-rays associated with ^{201}At decay exhibit curvature typical of a growth and decay relationship. We believe that this shape of the decay curves is the result of the feeding of the ^{201g}At ground-state by some unknown isomeric state decay. Additional analysis is in progress, as well as a planned Xγ·t experiment, in order to distinguish these γ-rays associated with ^{197}Bi following the alpha decay of ^{201}At from those belonging to ^{201}Po from the β^{+}/EC decay branch. (R. A. Braga and P. B. Semmes)

Table I - Gamma rays assigned to ^{201}Bi populated in the decay of $^{201m\,g}$Po (9 min, 14 min)

Energy (keV)	Intensity (relative)	Multipolarity
188.7 3	7.76	M1 + E2
195.8 3	0.54	(E1)
217.5 5	0.66	M1 + E2
240.1 2	70.38	M1 + E2
272.2 3	7.36	
296.0 6	1.90	
411.9 2	33.56	
428.1 2	13.24	E2
529.6 5	10.58	(E1)
534.7 6	10.58	
537.4 3	29.19	
543.8 5	3.59	
551.8 3	7.67	
583.3 3	5.48	
593.1 2	15.07	M1
697.6 5	4.67	
754.4 3	7.32	
771.7 5	4.46	M1
791.3 4	14.21	
846.2 2	8.35	M4
874.7 4	4.86	
890.2 2	98.10	E2
904.3 2	50.61	
964.1 3	81.71	
967.6 3	100	
978.7 5	4.54	
1175.2 3	10.59	
1186.9 4	18.93	M1
1398.3 5	5.35	
1502.1 8	3.53	

732, 972, 1023, 1319, 1507, 1652, 1689, 1703, 1747, and 1779 keV observed only in coincidence.

Table II - Gamma-ray Coincidence in ^{201}Bi from decay of ^{201mg}Po (9 min, 14 min)

Gate	coincidences observed
189	240, 543, 583, 792, 1319
218	964
240	189, 530, 732, 771, 980, 1398, 1507
272	412, 967
296	890
412	272, 967
429	583, 792
530	240
535	218, 967
538	218, 904, 964
543	189, 240
552	890
583	189, 240, 429
593	890
698	967
755	964
771	240
792	189, 240, 429
875	904
890	196, 296, 552, 593, 890, 1176
904	538, 875, 1023, 1689
964	538, 755
967	272, 412, 535, 698
980	240
1176	890
1398	240
1507	240
1689	904
1703	890

2.2 Slow M4 Transitions in ^{199,201}Bi and the $s_{1/2}$ Intruder State

The completed study of the band built upon the 1/2+ shell-model intruder state in ^{199,201}Bi and of the 846 keV M4 isomeric transition depopulating this state in ^{201}Bi has been accepted for publication in Nuclear Physics A (ref. 1 in Sect. 8.0 below). In addition to being the only known "ℓ-forbidden" M4 transition in odd-A nuclei, the isomeric transition in ^{201}Bi appears to be further hindered because it is a hole $\rightarrow$ particle transition.

2.3 Decay of ^{203}At

While the investigation of the decay of ^{203}At (7 min) remains a priority project, no data in addition to the previously measured γ-ray singles spectrum, have been obtained to date, owing to the extended UNISOR and ORIC shutdown periods. A run is scheduled for the latter part of 1980. This problem had been part of the doctoral thesis of Mr. Chris Papanicolopulos, who has resigned, and will be continued by Mr. Paul Semmes and other members of the nuclear chemistry group.

2.4 Decay of ^{187}Au (8.4 min)

The detailed study of the decay of ^{187m,g}Au to ^{187}Pt has been continued with a recent successful $\gamma\gamma\cdot t$ coincidence experiment. This was the first time that gold isotopes were mass separated at UNISOR, made possible by the development of a new high temperature ion source by R. L. Mlekodaj and using the $^{181}Ta(^{12}C^{+4},6n)^{187}Au$ reaction of 95 MeV. Preliminary analysis indicates that these data represent the highest quality (both in statistics and in resolution) ever taken on a single isotope at UNISOR, amounting to approximately 2×10^7 $\gamma\gamma\cdot t$ events.

A preliminary decay scheme, Fig. 2, was developed by Marvin Grimm as part of his PhD thesis[5)]. There are numerous assignments in his scheme that are in apparent disagreement with the recent publication of Braham, et al.[6)] It is hoped that the present work, and our planned ce $^{-}\gamma \cdot t$ coincidence experiments will be able to resolve these discrepancies, in order to better our understanding of the structure of the odd-mass Pt isotopes.

A preliminary experiment, mentioned in last year's annual report, ORO-3346-236 (1979), indicated that a short-lived isomer of ^{187m}Au (< 1 sec) may exist. We plan to investigate the existence and decay characteristics of this isomer.

The nuclide ^{187}Pt is especially important in that it lies on the borderline between the near-spherical nuclei for $A \geqslant 187$ and the strongly-deformed shapes of the far neutron-deficient region $A \leqslant 186$. It is also important in that the odd-mass Pt isotopes possibly can be used to study the coupling of an odd neutron to a Pt core, in order to ascertain whether or not there are distinct proton contributions to the collective degrees of freedom, as is suggested by the interacting boson-fermion approximation (IBFA)[7)].

[5] M. A. Grimm, Jr., PhD Thesis, Georgia Institute of Technology (1978)

[6] A. Ben Braham, et al., Nuclear Phys. A332, 397 (1979)

[7] F. Iachello, "How Well Can We Predict Nuclei Far from Stability?" in Future Directions in Studies of Nuclei far from Stability, edited by J.H. Hamilton, E. H. Spejewski, C. R. Bingham, and E. F. Zganjar (North-Holland Publishing Co., Amsterdam, 1980); p.281ff

It has been suggested that the proton (neutron) contributions can be probed by the coupling of the collective modes to an unpaired neutron (proton). The decay scheme $^{187m,g}Au \rightarrow {}^{187}Pt$ will form part of the PhD thesis of Mr. Bruce Gnade.

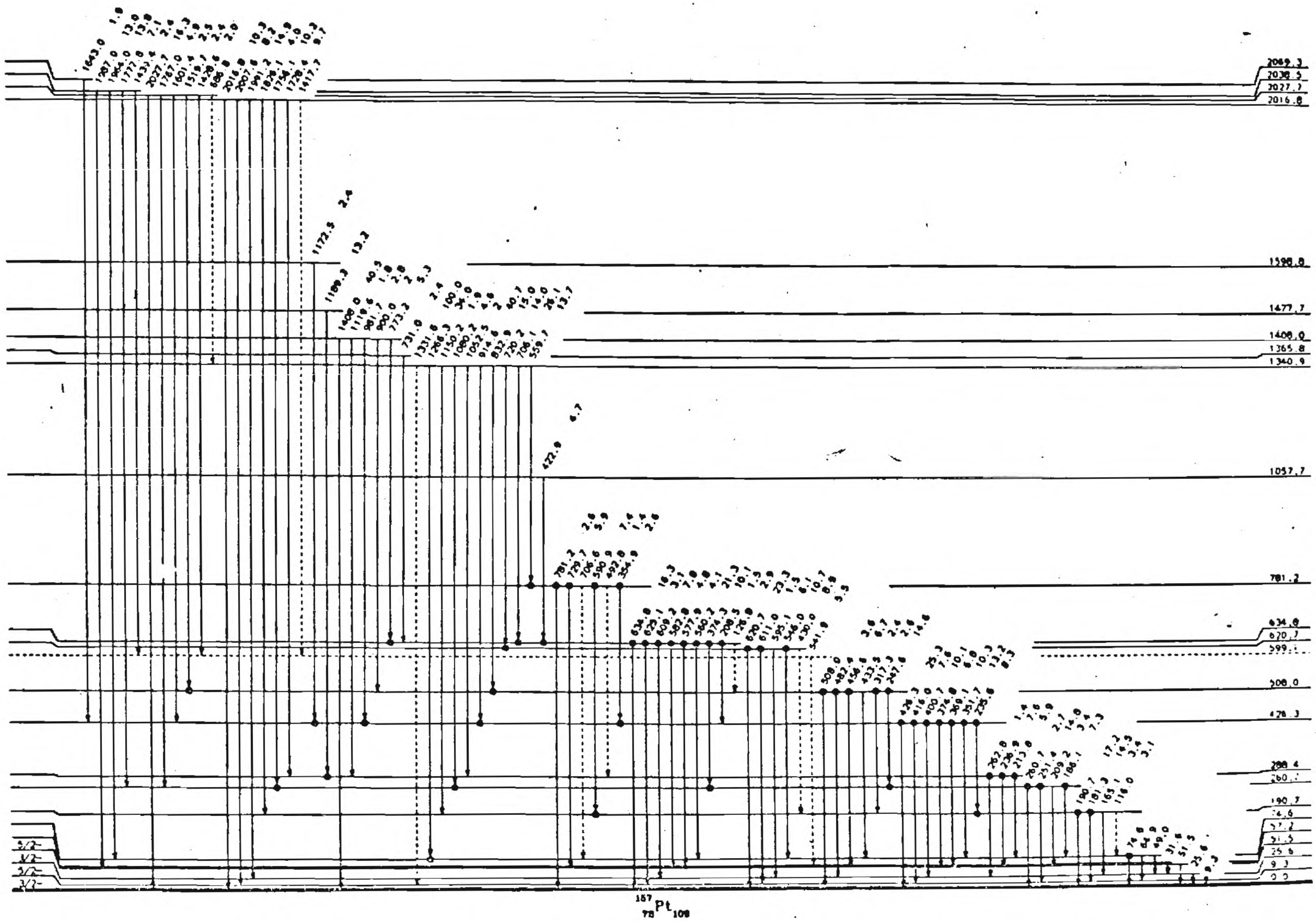


Figure 2 Decay Scheme for ^{187}Au. Coincidences are denoted by ● .

2.5 Lifetimes of the $g_{7/2}$ Intruder State Band Levels in ^{109}Ag from ^{109}Pd (13.43 h) Decay

The measurement of lifetimes of states in ^{109}Ag believed to be members of the $g_{7/2}$ intruder band has been performed with delayed coincidence techniques (300 picosec to 20 nanosec) at Georgia Tech. A system, consisting of a plastic scintillator and a Ge(Li) detector utilizing state-of-the-art amplitude and risetime-compensated (ARC) timing modules, was used to study lifetimes of levels populated in the decay of 13.43 h ^{109}Pd, sources of which were prepared in the Georgia Tech Research Reactor by the enriched ^{108}Pd(n,γ) reaction. The evaluation of the present data results in a value of approximately 0.8 nanosec for the lifetime of the 3/2+, 724.4 keV level, believed to be the second member of the intruder band, consistent with our previous determination of the approximate range of this lifetime.

Data of excellent statistical quality were obtained, and even though only 0.0018% of all decays populated the 1/2+, 707.0 keV band head member, no measureable lifetime of the 707.0 keV member was obtained. This observation is consistent with a possibility that a doublet exists near 707.0 keV, and that the member populated in the decay of ^{109}Pd is not the band head.

The latest data also indicate the presence of a γ-ray at 697 keV in coincidence with low-energy transitions. The tentative placement of this transition between the 697 keV level and the 1/2- ground-state in ^{109}Ag would conflict with the reported deexcitation of the 697 keV level to the 9/2+, 132 keV level and the 7/2+, 88 keV isomeric state [8] (see Fig. 3).

[8] F. El-Bedewi, Z Miligy, and H. Hanafi, Acta Phys. (Hungary) 38, 153 (1975)

Additional measurements to resolve this apparent disagreement are in progress.

Fig. 3 - Partial decay scheme for ^{109}Ag showing the 1/2+ and 3/2+ states at 707 and 724.4 keV which are possible candidates for members of the $g_{9/2}$ intruder band. Also shown is the 697 keV level which on the basis of its decay to both high-spin states (7/2+ and 9/2+) and possibly to a low-spin state (1/2-) indicates a questionable assignment of this level.

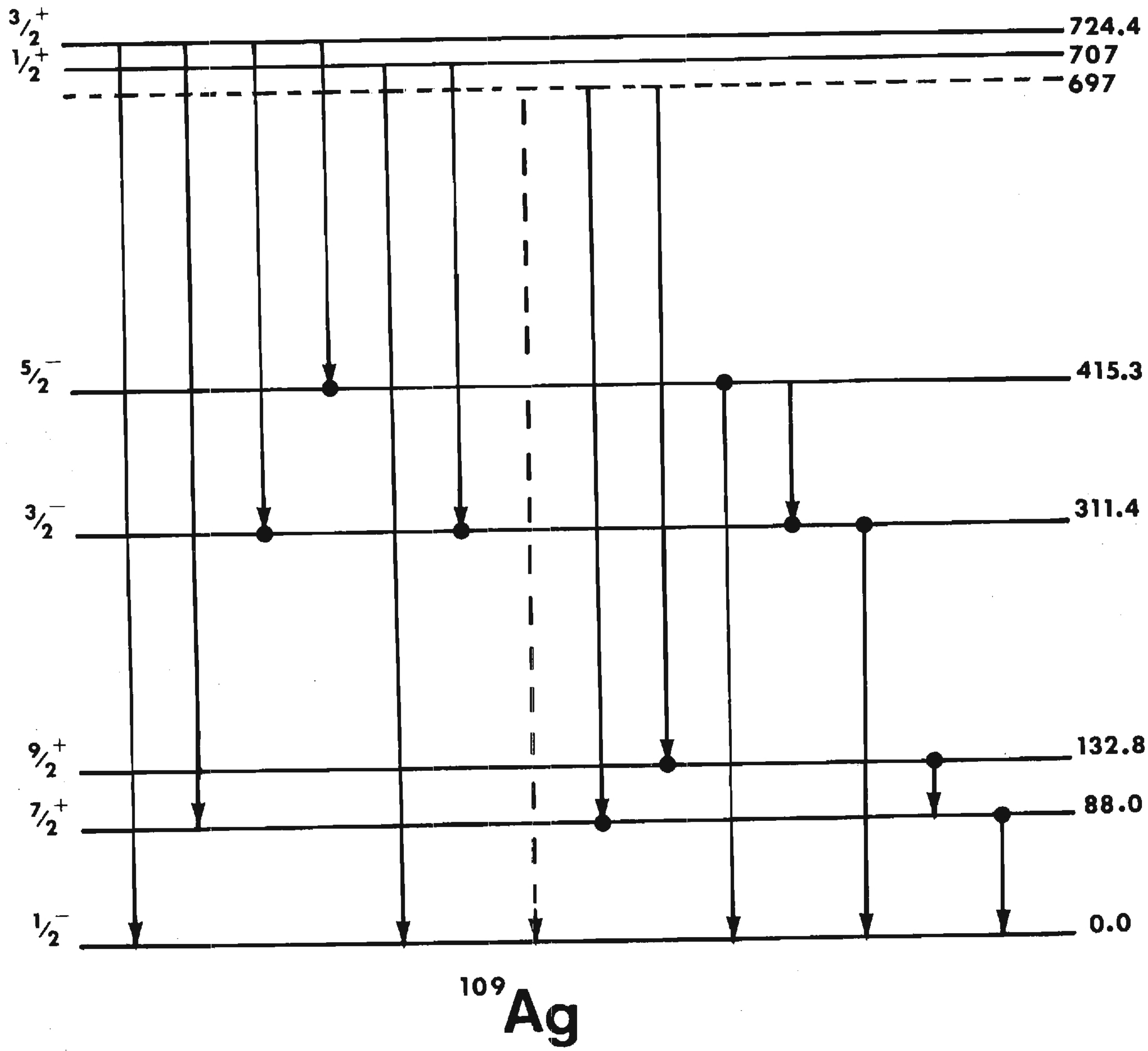


Fig. 3

3.0 Systematic Investigation of Interacting Boson-Fermion Approximation Predictions and Comparison with Odd-A Gold Isotopes

An extensive systematic comparison of the Interacting Boson-Fermion Approximation Model predictions with current experimental data on neutron-deficient gold isotopes was performed. To our knowledge, this is the only investigation of a systematic region using the IBFA model. The calculations were carried out with the computer codes "PHINT" and "ODDA" with initial parameters graciously supplied by F. Iachello and O. Scholten (of Yale University and K.V.I., Gröningen, The Netherlands, resp.) and in collaboration with an evaluation of the model by J. L. Wood (School of Physics, Georgia Tech).

In this comparison, our emphasis has been on the odd-A gold isotopes, and in particular, the coupling of the $h_{9/2}$ proton to the even Pt cores. The model predictions for this coupling for $^{187-195}$Au are shown in Fig. 4 for levels below 1.0 MeV, while Fig. 5 shows a comparison of the experimental data with the IBFA calculations for ^{189}Au. The agreement between experiment and theory is quite impressive, considering that in this prescription the parameters used are applied within a given shell and are not the result of a fitting to experimental data. (R. A. Braga)

Fig. 4 -- Calculated energy spectra for the coupling of the $h_{9/2}$ proton to the even Pt cores for $^{189-193}Au$. As the neutron number decreases and boson number increases, there is a transition away from the O(6) (γ-soft rotor) limit toward the SU(3) limit (axial rotor).

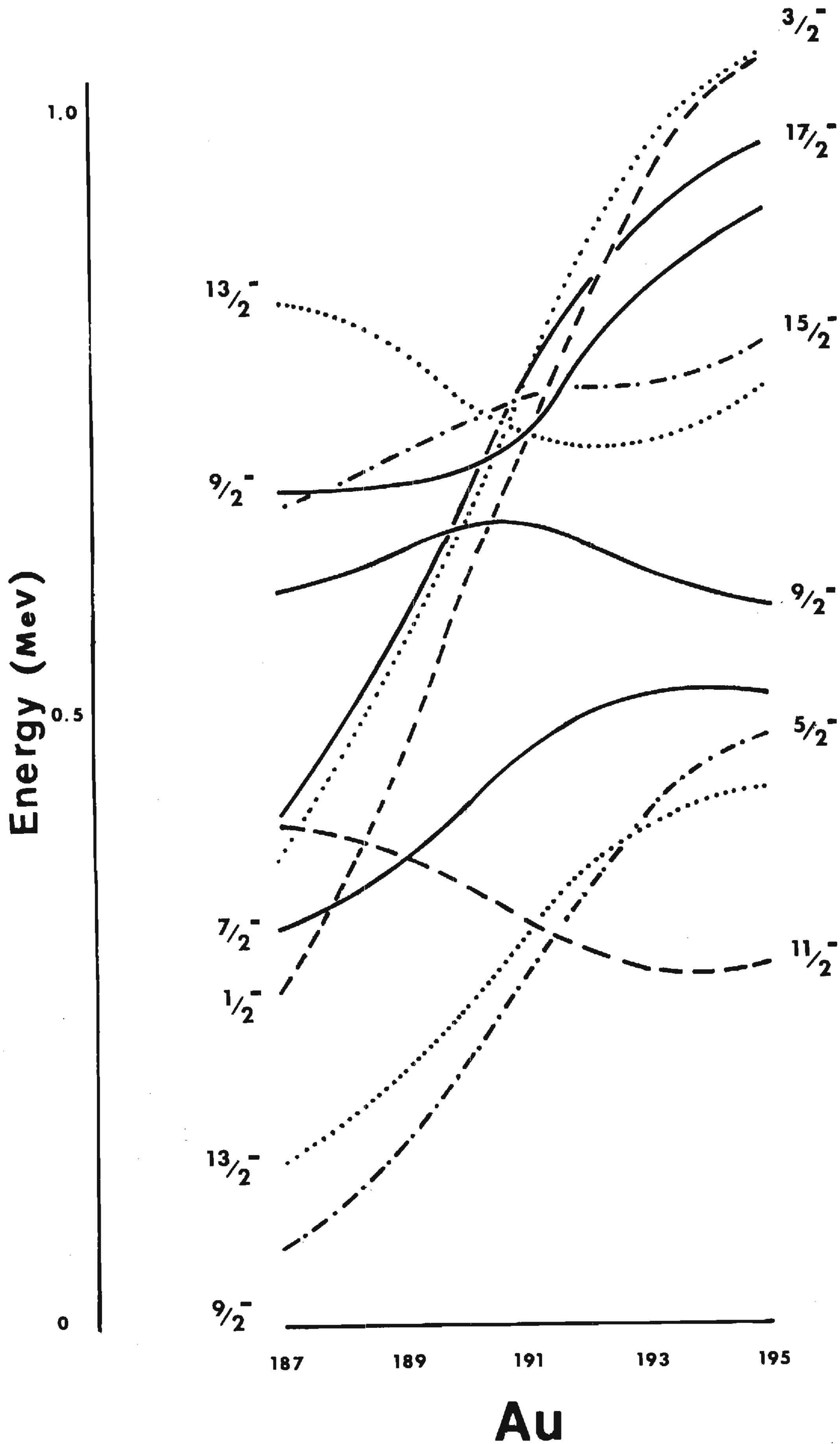

3/2⁻
1.0
17/2⁻
13/2⁻
15/2⁻
9/2⁻
9/2⁻
Energy (MeV)
0.5
5/2⁻
7/2⁻
11/2⁻
1/2⁻
13/2⁻
0
9/2⁻
187
189
191
193
195
Au

Fig. 4

Fig. 5 - Comparison of the IBFA calculated energy spectra with experimental energy levels for ^{189}Au for levels below 1.0 MeV. Agreement is very good considering that the only adjustable parameter is the number of bosons ($n_T = n_\pi + n_\nu = 10$; $n_\pi = 2$, $n_\nu = 8$).

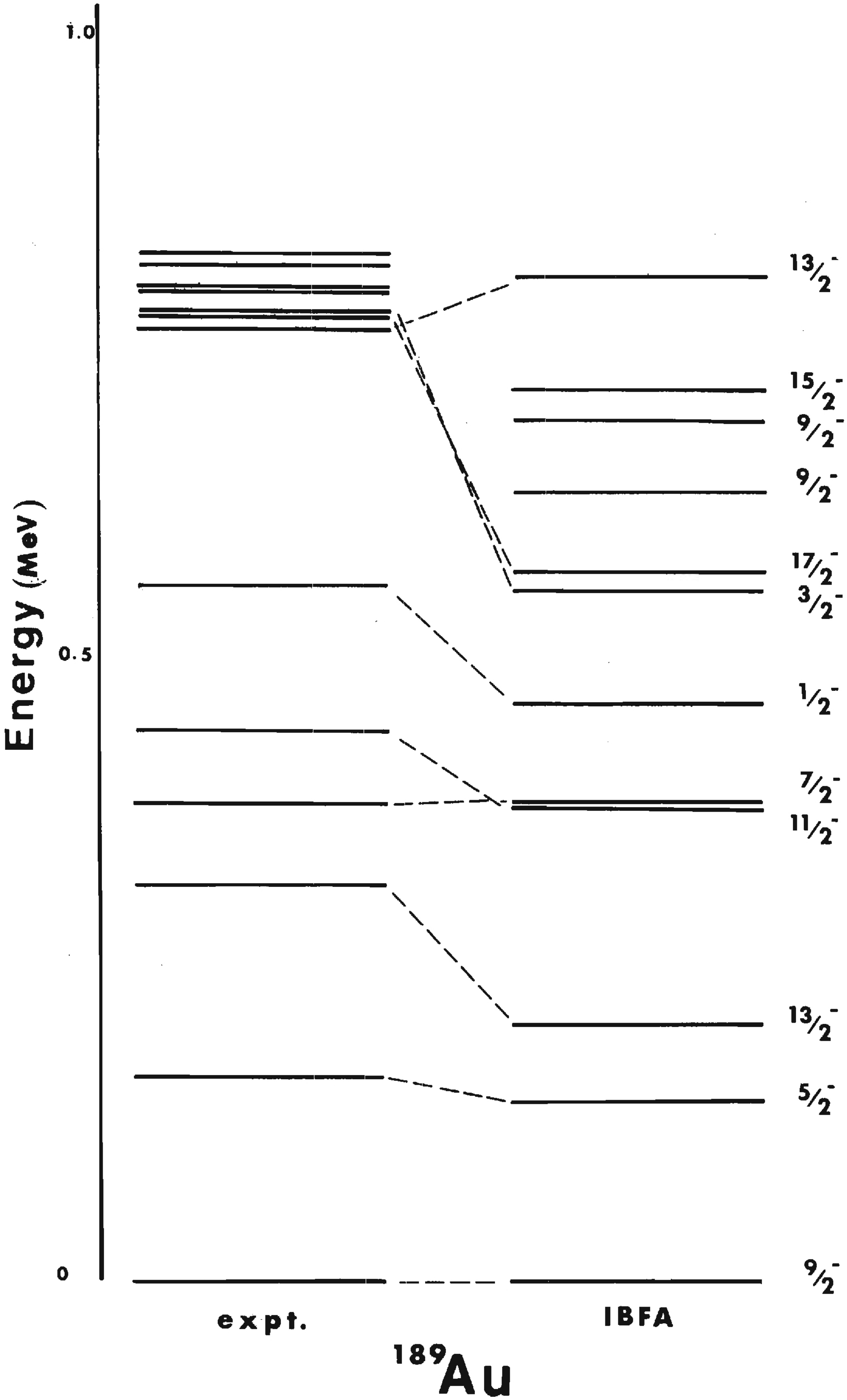

1.0
0.5
0
Energy (MeV)
13/2⁻
15/2⁻
9/2⁻
9/2⁻
17/2⁻
3/2⁻
1/2⁻
7/2⁻
11/2⁻
13/2⁻
5/2⁻
9/2⁻
expt.
IBFA
189Au

Fig. 5

4.0 International Intercomparison of ^{133}Ba Gamma-ray Standards

The participation of our group in the international comparison of γ-ray emission-rate measurements on ^{133}Ba (10.74 y) sources, organized by the Working Group on Alpha-, Beta-, Gamma-ray Spectroscopy of the International Committee for Radionuclide Metrology (ICRM), under the chairmanship of J. Legrand (France), and administered in the USA through the National Bureau of Standards, has been completed and a preliminary report circulated among the participants. A summary of our measured emission rates is given in Table III.

Our participation in this investigation is the result of our ongoing interest in characterizing the efficiency response of large-volume Ge detectors (such as those used at UNISOR) for the energy region below 200 keV. In this region, the efficiency response exhibits a rapid curvature, and the ability to obtain accurate intensities for the γ-rays observed in our decay scheme studies have previously been hindered by the lack of emission-rate standards in this energy region.

Table III - Emission Rates of Gamma-rays from ^{133}Ba (10.74 y)
Present work

Energy (keV)		Emission rate per 100 decays
30.625 30.973	$K_{\alpha_{2,1}}$	99.87
35.4	K_{β}	23.22
53.155		2.181
79.621		2.848
80.997		35.50
160.6		0.6559
223.2		0.4584
276.4		7.006
302.9		18.02
356.0		61.10
383.8		8.746

5.0 X-rays and Inner Shell Ionization Phenomena from Radioactive Sources

5.1 Studies of the L_1 Subshell

Measurement of L_1 subshell x-ray fluorescence and Coster-Kronig yields has been difficult for two important reasons: (1) at high Z, most of the L_1 atomic vacancy states decay by Coster-Kronig transitions that transfer vacancies to the L_2 and L_3 subshells, thus making it difficult to observe L_1 characteristic x rays separately; and (2) unlike L_2 and L_3 vacancy states, which are final states from the K_{α_2} and K_{α_1} radiative transitions, respectively, the L_1 vacancies are not final states in the radiative decay of K vacancy states, thus precluding the use of x ray and x-ray coincidence techniques. However, nuclear transitions, in which L_1 vacancy production has a high probability, have been used in the past as convenient sources for study of L_1 atomic vacancy states. With the presently available high resolution x-ray detectors and state-of-the-art timing coincidence techniques, these measurements can be extended to a wide range of elements, using nuclear transitions to generate the L_1 vacancies.

The present measurements of the L subshell yields for Z = 82 are made using the long-lived (33.4 y) ^{207}Bi sources which decay by electron capture to ^{207}Pb. An XX·t three-parameter arrangement with the ND-4420 multiparameter analyzer is used to collect the coincidence spectra as two of the parameters, as well as the TAC spectrum as the third parameter. A fourth ADC unit is also used to collect the necessary singles spectra. The true coincidence events fall into a broad peak (60 to 100 nsec) in the TAC spectrum and stand over a very small continuous distribution of events that are primarily due to chance coincidences. An analysis of the profile of the TAC spectrum was first carried out to make sure that all of the true coincidences in any required spectrum are completely included. This completeness is critical to an accurate determination of all L subshell quantities.

The L_1 subshell yields are obtained from the analysis of the L x rays in coincidence with the L conversion electrons resulting from the 1063 keV transitions which produce predominantly L_1 vacancies. Two alternative procedures were used in analyzing the coincidence spectrum. In the first, the coincidence rates of $L_{\alpha+\ell}$, $L_{\beta+\eta}$, and L_γ x rays were evaluated separately, and using the relations given by Rao, et al. [9], the values of ω_1, f_{12}, and f_{13} are deduced. In the second procedure, the spectrum of coincident L_γ x rays was analyzed into its two components characteristic of L_2 and L_1 subshells, and ω_1 was obtained directly from the number of L_1 characteristic x ray present. The second procedure also leads to a direct determination of the radiative branching ratio s_1 for the L_1 subshell.

The L_1 subshell yields at Z = 56 will be determined using the radioactive source ^{137}Cs (29.9 y) which decays to ^{137}Ba. The L x rays in coincidence with 656 keV L-conversion electrons will be analyzed using the techniques employed in the case of ^{207}Bi. (M. Tan, P. V. Rao, R. A. Barga and R. W. Fink)

5.2 Studies of the L_2 and L_3 Subshells

The L_2 and L_3 subshell yields were obtained from the L x-ray — K_{α_2} x ray and L x-ray — K_{α_1} coincidence rates, respectively. In particular, the measurement of f_{23}, the Coster-Kronig transition probability of $L_2 \rightarrow L_3$ vacancy transfers, was obtained in two alternative procedures. The first made use of the observed ratio of L_3 characteristic x rays and L_2 characteristic

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[9] P. V. Rao, R.E. Wood, J. M. Palms and R. W. Fink, Phys. Rev. 178, 1997 (1969)

x rays present in the spectrum of L x rays in coincidence with a K_{α_2} x-ray gate. The second procedure was based upon observing the ratio of K_{α_2} and K_{α_1} x rays in coincidence with an L_α x-ray gate. The analysis of the coincidence spectrum was based upon the improved method for tailing corrections given by Gnade, et al.[10].

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[10] B.E. Gnade, R. A. Braga, W. R. Western, J. L. Wood and R. W. Fink, Nucl. Instr. Meth. 164, 163 (1979)

A completely new set of measurements of f_{23} is being undertaken using the improved techniques available for the analysis of coincidence spectra. These measurements, as a function of atomic number Z, are very important and necessary to compare with the theoretical estimates based on the recent relativistic calculations[11] of the radiationless transitions of L-subshell vacancy states. The next measurement will be that of ^{170}Tm (130 d) to ^{170}Yb to measure f_{23} at Z = 70.

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[11] M.H. Chen, E. Laiman, M. Aoyagi and Hans Mark, Phys. Rev. A19, 2053 (1979)

The new results at Z = 82 from ^{207}Bi decay will be published in the near future. (M. Tan, P.V. Rao, R.A. Braga and R. W. Fink)

5.3 The Decay Energy of ^{207}Bi (33.4 y)

The only available estimate of the total decay energy in the electron capture decay of ^{207}Bi to ^{207}Pb is based upon a very early measurement of the L x-ray - 1770 keV γ-ray coincidence rate (which determined the L-capture fraction P_L = 0.663 from which Q_{EC} = 62.4 keV to the 2339 keV level in ^{207}Pb) obtained using proportional and NaI(Tl) counters[12]. It was assumed from the

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[12] De Beer, Blok, and Blok, Physica 30, 1938 (1964)

---

experimental data existing at that time that there is no K capture to the 2339 keV level. This evidence remains to be verified and substantiated. The currently accepted ^{207}Bi-^{207}Pb mass difference (2400.4 keV) rests on the validity of this assumption and on this single early measurement of the L capture probability. In view of the fact that the nuclide ^{207}Bi is an important calibration standard and the necessity to use an accurate value of the decay energy in estimating the K and L electron capture probabilities and other inner shell ionization rates, a measurement of the rates of K and L x rays in coincidence with 1770 keV γ-rays is in progress, utilizing a large volume high resolution Ge(Li) γ-ray detector and high resolution Ge(HP) x-ray detector, together with three-parameter $X\gamma \cdot t$ analysis. This work will provide a precise value of the decay energy Q_{EC} and the individual L-subshell orbital electron capture probabilities for comparison with theory. (M. Tan, P. V. Rao, R. A. Braga and R. W. Fink)

6.0 Miscellaneous Topics

6.1 Preparation of Reactor-Produced, Carrier-Free ^{18}F as the Potassium 18-Crown-6 Complex for Synthesis of Labelled Organic Compounds

An anion exchange and distillation procedure has been developed for preparing reactor-produced carrier-free ^{18}F as $K^{18}F$ complexed with 18-crown 6 in acetonitrile for subsequent syntheses of labelled organic compounds. The reaction sequence $^{6}Li(n,t)^{4}He-^{16}O(t,n)\ ^{18}F$ produced yields of approximately 250 milliCuries of ^{18}F per hour per gram of 96% enriched ^{6}Li as $^{6}LiOH \cdot H_2O$ target in a reactor thermal neutron flux of 3×10^{13} n/cm$^2 \cdot$sec. Yields of tritium-free carrier-free ^{18}F dissolved in the crown ether solution typically reach 85 ± 5% within 20-30 minutes required for the radiochemical procedure. A full manuscript has been accepted for publication in the International Journal of Applied Radiation & Isotopes by B. E. Gnade, G. P. Schwaiger, C. L. Liotta, and R. W. Fink

6.2 CDC-Cyber-70/74 Computer Codes

The computer code "NPBOS" (written by O. Scholten, K.V.I., Gröningen, The Netherlands) has been adapted for operation on the Georgia Tech CDC Cyber 70/74 computer. This code calculates energies and eigenvalues for positive and negative parity states for even-A nuclei in the framework of the interacting boson-fermion approximation model. This calculation differs from that of the code "PHINT" in that a distinction is made between proton and neutron bosons.

During the past year, we have made a major effort to reduce the core requirements of our data handling codes; an effort made necessary because of the decreased computer availability resulting from the increased demands upon on the Georgia Tech Cyber system. Since the majority of our computer usage is in data processing (ie, sorting of coincidence spectra, peak-shape analysis, etc.) as opposed to numerical calculations, our jobs require extensive mass storage, as well as peripheral devices, although for short periods of time (1 - 2 min). Our core-efficient data handling codes now provide satisfactory data processing without extremely long "turn-around" times. (R.A. Braga)

6.3 Equipment added during 1980

During this year, we added a Nuclear Data Model ND-570 Analog-to-Digital converter (ADC) to our ND-4420 multiparameter multichannel analyzer. This 80 MHz ADC now gives us four compatible ADC's providing the ability to perform more sophisticated multiparameter multiconfigurational experiments.

In addition, we are replacing old (> 10 years) NIM logic modules with new state-of-the-art models. A logic shaper and delay (Canberra Model 2055) and a constant-fraction timing single-channel analyzer (Canberra Model 2035A) have been ordered. The modules will provide better timing characteristics, noise reduction, and count-rate stability for logic signal processing in our timing circuits.

Our Chemistry Machine Shop fabricated beam-line flanges and a port viewing window for on-line operation of the laser spectroscopy facility at UNISOR.

7.0 Personnel

Senior Staff

Dr. R. W. Fink, Professor of Chemistry
Principal Investigator (1/4 time, 12 months)

Dr. R. A. Braga, Research Associate
(65% DOE + 35% teaching in School of Chemistry, 12 months;
full-time DOE from September, 1980)

Dr. Mustafa Tan, Asst. Prof. Physics on leave from Atatürk Univ., Turkey
Research Associate (1/2 time DOE, 9 months from May, 1980)

Dr. P. Venugopala Rao, Assoc. Prof. Physics, Emory University
Research Associate (1/2 time DOE, 2 months, summer, 1980)

Graduate Students

Mr. Bruce E. Gnade (Chemistry). Continuing PhD thesis research utilizing UNISOR facilities (1/2 time Research Assistant, DOE, 12 months)

Mr. Paul Semmes (Chemistry) [B.S. Chem, June, 1980. Georgia Tech]
Beginning PhD thesis research utilizing UNISOR facilities
(1/2 time Research Assistant, DOE, from September, 1980;
1/2 time Teaching Assistant, June - August, 1980;
Special problem student in nuclear chemistry 1979 - June, 1980)

Mr. Gary P. Schwaiger (Nuclear Engineering). Completing M.S. in N.E. Special problem student in nuclear chemistry since August 1979. Plans to join nuclear chemistry upon completion of M.S. degree and to do PhD research utilizing UNISOR facilities. No DOE support

Mr. Chris Papanicolopulos (Physics) Terminated March, 1980

Mr. W. S. Lewis (Chemistry) Terminated April, 1980

Special Problem Students

Mr. William Pekny (Chemistry). Senior Special Problem Student in nuclear chemistry, finishing June, 1980. No DOE support. Worked on A = 201 UNISOR data analysis.

Mr. Steve Sewell, Summer program high school student 1980. No DOE support. Worked on UNISOR data analysis.

Miss Lisa Coffman, Summer program high school student 1980. No DOE support Worked on UNISOR data analysis.

8.0 List of Publications and Presentations at Meetings

1) "Very Slow M4 Transitions and Shell-Model Intruder States in $^{199,201}Bi$," R. A. Braga, W. R. Western, J. L. Wood, R. W. Fink, R. Stone, C. R. Bingham, and L. L. Riedinger, Nuclear Phys. A (in press, 1980) and Bull. Am. Phys. Soc. 24, 836 (1979) Knoxville, Tenn., October, 1979). [ORO-3346-238]

2) "Decays of $^{117}Xe \rightarrow {}^{117}I \rightarrow {}^{117}Te$," R. S. Lee...W. D. Schmidt-Ott, A. C. Xenoulis, R. W. Fink, and other UNISOR coauthors, Phys. Rev. C (submitted, 1980) [ORO-3346-239]

3) "The Use of Systematics in the Interpretation of Nuclear Structure far from the Beta Stable Region," J. L. Wood (invited paper) in Future Directions in Studies of Nuclei far from Stability, edited by J. H. Hamilton, et al. (North-Holland Publishing Co., Amsterdam, 1980); pp. 37-48

4) "Excited States in $^{189,190}Pt$ from Decays of $^{189m,\ 190g}Au$," B. E. Gnade, J. L. Wood, and R. W. Fink, Bull Am. Phys. Soc. 25 (1980)[ORO-3346-241]

5) "Studies of Z = 81 Transitional Nuclei I. ^{197}Pb Decay," L. L. Collins, L.L. Riedinger, G. D. O'Kelley, C. R. Bingham, M. S. Rapaport, J. L. Wood, and R. W. Fink, Phys. Rev. C (submitted, 1979)[ORO-3346-221

6) "Studies of Z = 81 Transitional Nuclei II. ^{193}Pb and ^{195}Pb Decays," L. L. Collins, L.L. Riedinger, A. C. Kahler, C. R. Bingham, G. D. O'Kelley, J. L. Wood, R. W. Fink, A. G. Schmidt, E. H. Spejewski, H. K. Carter, R. L. Mlekodaj, E. F. Zganjar, and J.H. Hamilton, to be submitted, 1980 [ORO-3346-222]

7) "The $h_{9/2}$ Bands in $^{185-195}Au$ and the Interacting Boson-Fermion Approximation, R. A. Braga and J. L. Wood, Bull. Am. Phys. Soc. 25 (in press, 1980) (Minneapolis, Minn, October, 1980) [ORO-3346-240]

8) "An Inexpensive Pulser for the Adjustment of Subnanosec Walk in Timing Circuits," R. A. Braga, G. E. O'Brien, and R. W. Fink, Nucl. Instr. Meth. 163, 527 - 529 (1979)

9) "An Improved Measurement of the L_{2-3}-Subshell X-ray Fluorescence and Coster-Kronig Yields at Z = 64 and 67," B. E. Gnade, R. A. Braga, and R. W. Fink, Phys. Rev. C21, 2025 - 2032 (1980) and Bull Am. Phys. Soc. 24, 835 (1979) Knoxville, Tenn, October, 1979) [ORO-3346-233]

10) "Preparation of Reactor-Produced, Carrier-Free ^{18}F-Fluoride as the Potassium 18-Crown-6 Complex for Synthesis of Labelled Organic Compounds," B. E. Gnade, G. P. Schwaiger, C. L. Liotta, and R. W. Fink, Int. J. Appl. Radiat. Isotopes (accepted and in press, June, 1980)

11) BOOK CHAPTER: "Analysis of Zn and Cu," R. W. Fink and J. Carden, Chapt. 2,3 in Zinc and Copper in Medicine, edited by R. M. Sarper and Z. A. Karcioglu (C.C. Thomas Publishers, Springfield, Ohio, 1980); pp.

12) BOOK CHAPTER: "Properties of Si and Ge Semiconductor Detectors for X-ray Spectrometry," R. W. Fink (invited paper), Proc. Symp. on Energy-Dispersive X-ray Spectrometry (National Bureau of Standards, 1980) pp [ORO-3346-231]

13) BOOK CHAPTER: "Tables of Experimental Values of X-ray Fluorescence and Coster-Kronig Yields for the K-, L-, and M-Shells," R. W. Fink and P. V. Rao, in Handbook of Spectroscopy, Vol. 3 (CRC Publishing Co., Boca Raton, Florida, 1980); pp.

14) BOOK CHAPTER: "Thermal Neutron Cross Sections and Resonance Integrals for Activation Analysis," R. W. Fink, in Handbook of Spectroscopy, Vol. 3 (CRC Publishing Company, Boca Raton, Florida, 1980); pp. [ORO-3346-206(rev.)]

15) R. W. Fink (invited member of the panel), Workshop on Instrumentation and Analysis for Nuclear Fuel Reprocessing Hot Pilot Plant, May 5 - 7, 1980, Oak Ridge National Laboratory, cosponsored by the Subcommittee on Nuclear and Radiochemistry of the Committee on Chemical Sciences of the National Research Council

SI-SIE-78a

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NOTICE OF RESEARCH PROJECT
SCIENCE INFORMATION EXCHANGE
SMITHSONIAN INSTITUTION

SIE NO.

DOE CONTRACT NO. DE-AS05-76ERO-3346

SUPPORTING DIV. OR OFFICE: U.S. Department of Energy
Energy Research and Development Administration

NAME & ADDRESS OF CONTRACTOR OR INSTITUTION: (State the division, department, or professional school, medical, graduate or other, with which this project should be identified.)

School of Chemistry
Georgia Institute of Technology
Atlanta, Georgia 30332

TITLE OF PROJECT:

Nuclear Chemistry Research and Spectroscopy with Radioactive Sources

NAMES, DEPARTMENT, AND OFFICIAL TITLES OF PRINCIPAL INVESTIGATORS AND OTHER PROFESSIONAL SCIENTIFIC PERSONNEL: (not including graduate students) engaged on the project, and fraction of man-year devoted to the project by each person.

Dr. Richard W. Fink, Professor of Chemistry, Principal Investigator (1/2 time)
Dr. Robert A. Braga, Research Associate (full-time)
Dr. Mustafa Tan, Research Associate (1/2 time)
Dr. P. Venugopala Rao, Senior Research Associate (1/2 time summers only)

NO. OF GRADUATE STUDENTS ON PROJECT: 3 NO. OF GRADUATE STUDENT MAN-YEARS: 2

SUMMARY OF PROPOSED WORK: (200-300 words, omit Confidential Data). Summaries are exchanged with government and private agencies supporting research, are supplied to investigaters upon request, and may be published in AEC documents. Make summaries substantive, giving initially and for each annual revision the following: OBJECTIVE; SCIENTIFIC BACKGROUND FOR STUDY; PROPOSED PROCEDURE; TEST OBJECTS AND AGENTS.

Radioactivity is the phenomenon which underlies all of the current work in nuclear chemistry research and spectroscopy at Georgia Tech. Our principal effort remains centered on far-unstable nuclei produced by heavy ion beams from the Holifield Heavy Ion Research Facility (HHIRF) and studied on-line with the University Isotope Separator at Oak Ridge (UNISOR). The regions on both sides of the Z = 82 closed shell and around Z = 56 contain the nuclei of current experimental interest. The use of radioactive decay to excite the low-spin, low-energy states in the daughter nuclei is the only means of exploring the low-spin level structures in far-from-stable nuclei. We continue to explore the applicability of such particle-core coupling theories as the Interacting Boson-Fermion Approximation (IBFA) model. On campus x-ray coincidence studies and nuclear lifetime measurements augment our UNISOR-related research.

RESULTS TO DATE:

See Annual Progress Report, ORO-3346-242 (October 31, 1980) for the 16th year of this program.

10 publications by the Nuclear Chemistry group during 1979/80 plus 4 book chapters during this period in press by Prof. R. W. Fink.

	PROGRAM CATEGORY NO.
BUDGET	
PRIMARY	
SECONDARY	

Richard W. Fink
Signature of Principal Investigator

DATE: SEP 24 1980

INVESTIGATOR – DO NOT USE THIS SPACE

G33-659

ORO–3346–244

NUCLEAR CHEMISTRY RESEARCH AND SPECTROSCOPY WITH RADIOACTIVE SOURCES

Seventeenth Annual Progress Report
U. S. Department of Energy
Contract DE–AS05–76ERO–3346

R. W. Fink
Professor of Chemistry & Principal Investigator

July 31, 1981

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF CHEMISTRY
ATLANTA, GEORGIA 30332

1981

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1.0 Introduction

This report updates the research progress since the previous annual report of October 31, 1981 and is written only six months into the current DOE contract year (renewal date: February 1, 1982), in order to comply with the new DOE requirement for additional lead time for report and proposal evaluation.

It can be seen in this report that our current results fall into two categories: those problems which are largely completed and are in preparation for journal publication (decay of $^{201m,g}Po$, Sect. 2.1; lifetimes of $g_{7/2}$ intruder states in ^{109}Ag, Sect. 2.6; orbital electron capture ratios and decay energy of ^{207}Bi, Sect. 2.7) and those problems which are in the midst of active or initial investigation (decay of $^{187m,g}Au$, Sect. 2.2, decay of $^{201,203}At$, Sects. 2.3 and 2.4; decay of ^{125}Ba, Sect. 2.5; and IBFA model computations, Sect. 3.0).

With the current schedule of frequent UNISOR runs of high statistical quality, it is fortunate that we completed the analysis of all runs made prior to the 16-month shutdown (1979-80) for installation of the tandem-ORIC facility (HHIRF) and the on-line laser spectroscopy system on UNISOR, because current runs result in a large backlog of data awaiting analysis by our small nuclear spectroscopy team. It is therefore unfortunate that all members of our group beginning September, 1981, must be supported on teaching assignments in freshman chemistry because of inadequate DOE funding in the current contract year, the more so because of the increasing activity at UNISOR and the advent of runs on the HHIRF tandem accelerator.

In the period since the previous annual report (October 31, 1981) we have carried out three UNISOR runs, in each of which new levels of performance were reached. In particular, in a run on ^{187}Au decay, the $ce^{-}\gamma\cdot t$ coincidence data achieved the highest statistical quality of any such experiment so far (see Sect. 2.2 below); the $\gamma\gamma\cdot t$ coincidence data on ^{203}At decay also reached new levels of statistical quality, surpassing the record achieved the previous year in the case of ^{187}Au (see Sect. 2.3 below); and for the first time, as the result of the development of the new high temperature ion source, ^{125}Ba activity has been extracted directly in reasonable yield for initial studies of far-from-stable nuclei around the Z = 50 closed shell (see Sect. 2.5).

The sections below, and especially the decay scheme figures, summarize a massive amount of data analysis and results as of July, 1981.

2.0 Nuclear Spectroscopy Studies

The experimental data for the investigations reported in Sects. 2.1 - 2.5 below were taken with the UNISOR facility at the Holifield Heavy Ion Research Facility at Oak Ridge, and the data analysis was carried out at Georgia Tech. The measurements of lifetimes reported in Sect. 2.6 below were carried out on-campus in the School of Chemistry.

2.1 Decay of $^{201m,g}Po$

An analysis of the decay of $^{201m,g}Po$ (9 min, 14 min) has been completed and a manuscript is in preparation for journal publication. The level scheme of ^{201}Bi constructed from this analysis is shown in Figs. 1 and 2. (A number of weak, unassigned γ-rays observed in the spectra are not shown in the figures.)

A major portion of this scheme is the band built upon the $s_{1/2}$ shell-model intruder state and the M4 isomeric transition depopulating this state in ^{201}Bi (Fig. 1).[1)]

In Fig. 2, we show the negative-parity states resulting from the coupling of the $h_{9/2}$ single-proton state to the 2+ one-phonon and 4+ two-phonon states of the ^{200}Pb core. Also, tentative evidence for states resulting from the $i_{13/2}$ proton is shown by the levels at 1719.0 and 1501.6 keV. This structure is populated by both the decay of the high-spin 13/2+ isomer, 9 min ^{201m}Po, and by the decay of the 3/2- ground-state, 14 min ^{201g}Po.

(R. A. Braga, P. B. Semmes, & R. W. Fink)

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[1] R. A. Braga, W. R. Western, J. L. Wood, R. W. Fink, R. Stone, C. R. Bingham, and L. L. Riedinger, Nucl. Phys. A349, 61 (1980).

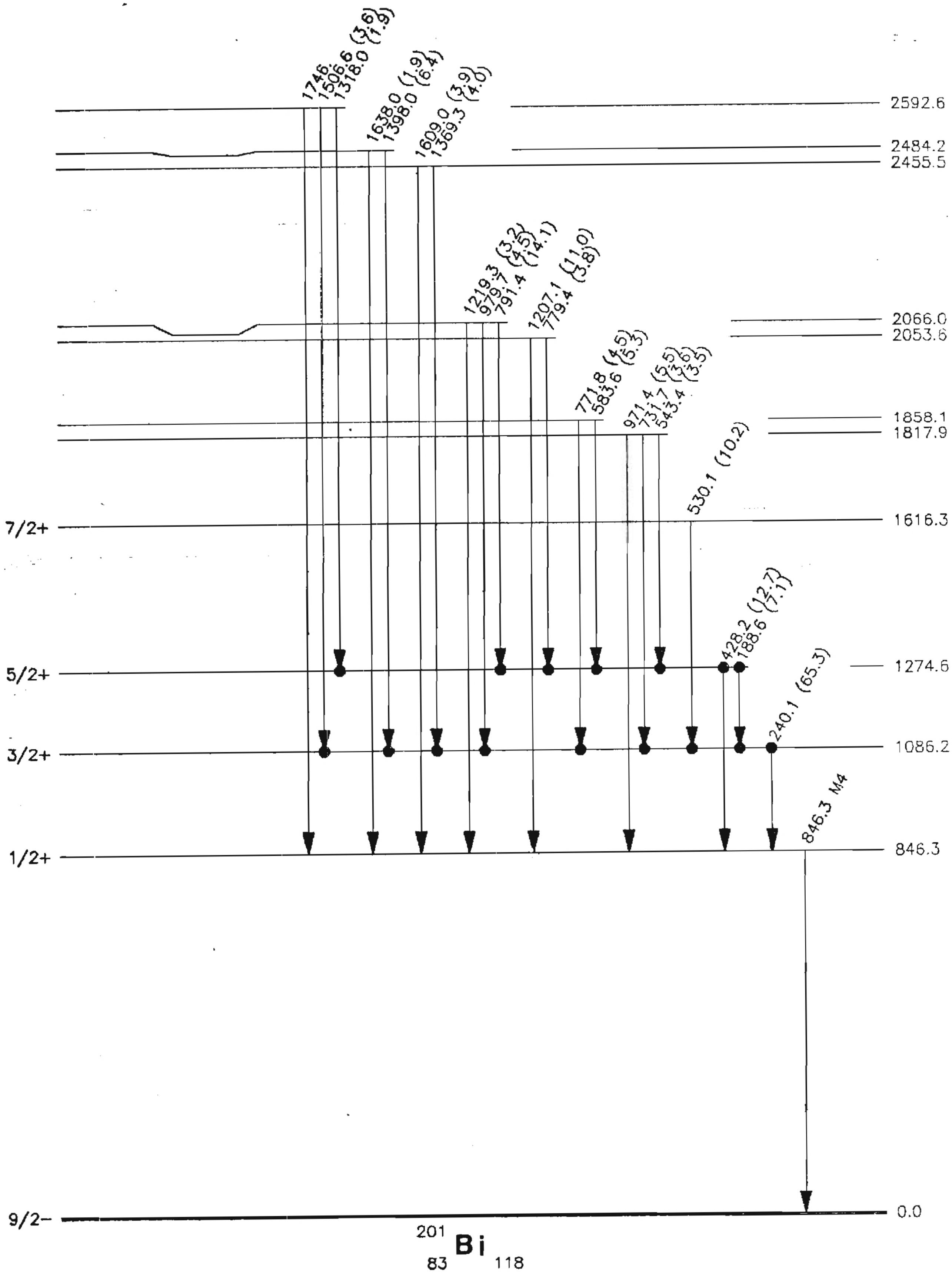
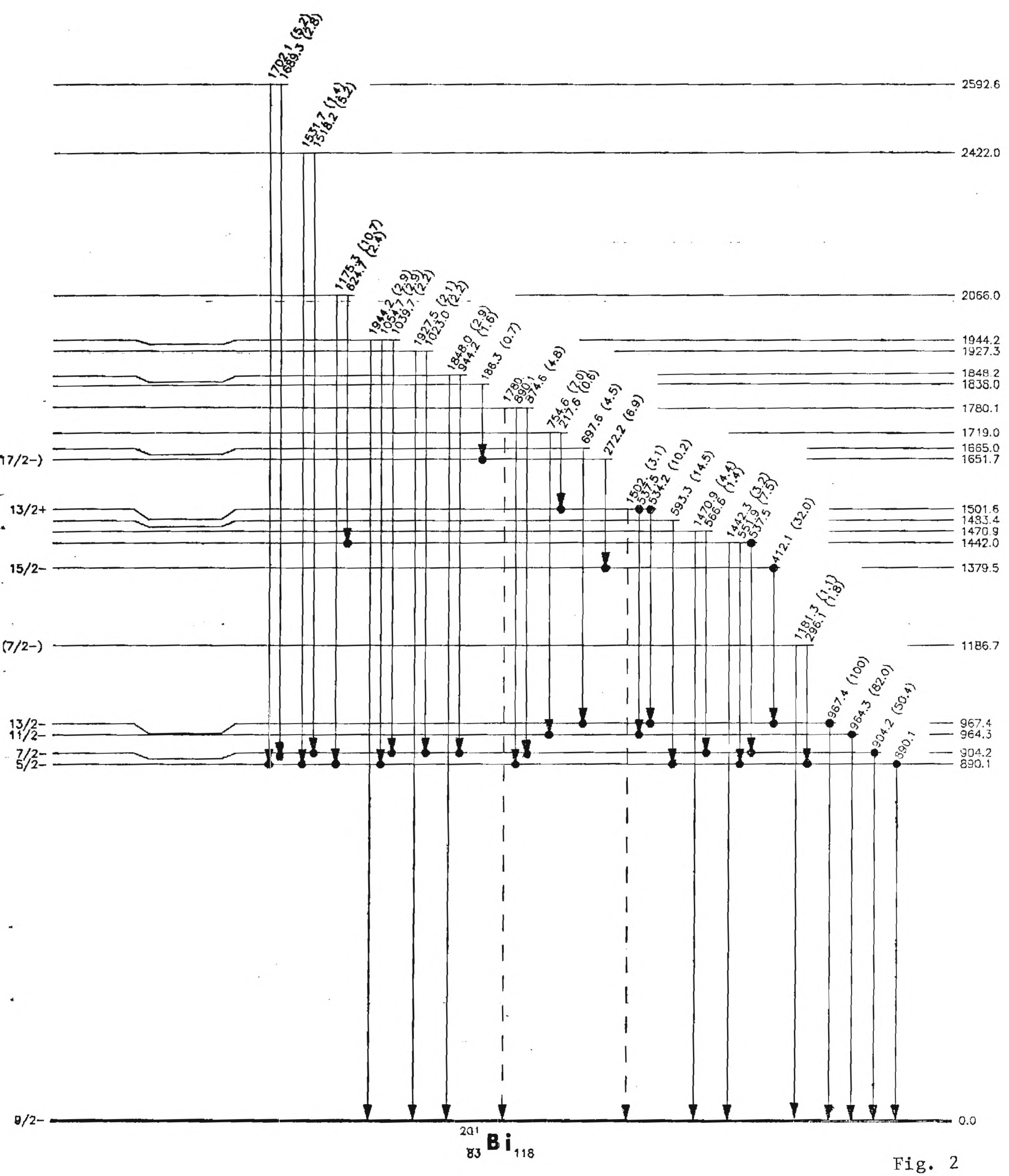

1746.
1506.6 (3.6)
1318.0 (1.9)
1638.0 (1.9)
1398.0 (6.4)
1609.0 (3.9)
1369.3 (4.0)
1219.3 (3.2)
979.7 (4.5)
791.4 (14.1)
1207.1 (11.0)
779.4 (3.8)
771.8 (4.5)
583.6 (5.3)
971.4 (5.5)
731.7 (3.6)
543.4 (3.5)
530.1 (10.2)
428.2 (12.7)
188.6 (7.1)
240.1 (65.3)
846.3 M4
2592.6
2484.2
2455.5
2066.0
2053.6
1858.1
1817.9
7/2+
1616.3
5/2+
1274.6
3/2+
1086.2
1/2+
846.3
9/2–
0.0
201
Bi
83
118

Fig. 1



2592.6
2422.0
2066.0
1944.2
1927.3
1848.2
1838.0
1780.1
1719.0
1665.0
1651.7
1501.6
1483.4
1470.9
1442.0
1379.5
1186.7
967.4
964.3
904.2
890.1
0.0
(17/2−)
13/2+
15/2−
(7/2−)
13/2−
11/2−
7/2−
5/2−
9/2−
1702.1 (5.2)
1689.3 (2.8)
1531.7 (1.4)
1518.2 (5.2)
1175.3 (10.7)
624.7 (2.4)
1944.2 (2.9)
1054.1 (2.9)
1039.7 (2.2)
1927.5 (2.1)
1023.0 (2.2)
1848.0 (2.9)
944.2 (1.6)
186.3 (0.7)
1780
890.1
874.6 (4.8)
754.6 (7.0)
217.6 (0.6)
697.6 (4.5)
272.2 (6.9)
1502 (3.1)
537.5
534.2 (10.2)
593.3 (14.5)
1470.9 (4.4)
566.6 (1.4)
1442.3 (3.2)
551.9
537.5 (7.5)
412.1 (32.0)
1181.3 (1.1)
296.1 (1.8)
967.4 (100)
964.3 (82.0)
904.2 (50.4)
890.1
$^{201}_{83}Bi_{118}$

Fig. 2

2.2 Decay of ^{187m,g}Au

We have continued our study of the decay of 8.4 min ^{187g}Au and 2.3 sec ^{187m}Au with a very successful ce$^-$-γ-t experiment carried out at UNISOR March 2, 1981. As in previous ^{187}Au experiment, gold isotopes were directly emitted from the high-temperature ion source. The reaction used for the production of ^{187}Au was ^{nat}Hf($^{14}N^{+4}$,5n)^{187}Au at 103 MeV. This was a particularly profitable reaction because the two major stable isotopes of Hf are ^{178}Hf and ^{180}Hf, which simultaneously produced large amounts of ^{187}Au and ^{189}Au. The Hf target was prepared as the carbide, HfC, which proved to be very stable, lasting the entire 6-shift run.

For the γγt experiment of August 1, 1980, we acquired 1.4×10^7 coincidence events. The strongest peak in the singles spectrum is the 1332.0 keV one with 1.77×10^5 net counts (taken with a 17% Ge(Li) detector). This gives 1.92×10^8 events when corrected for efficiency, which gives a better idea of the excellent statistics obtained. In this experiment we used one Ge(Li) detector and one ORTEC Gamma-X detector for high resolution at low energies. The Ge(Li) detector had a resolution of 2.12 keV FWHM at 1332 keV, while the Gamma-X had 1.45 keV FWHM at 661 keV and 850 eV FWHM at 110 keV. The benefit of using the high resolution Gamma-X detector is discussed in more detail in Sect. 4.2 below.

The ce$^-$γt experiment of March 2, 1981, resulted in acquisition of 1.5×10^7 coincidence events. To date, this is the most ce$^-$γt list data acquired for a single isotope at UNISOR. The 1332 keV γ-ray has approximately 1.1×10^5 counts in the peak of the Ge(Li) singles spectrum. The strongest peak in the electron spectrum is the L 51.0 keV ce$^-$ line, with approximately 1.6×10^6 counts in it. The electron spectrum is particularly complicated due to the six different levels below 100 keV, resulting in many highly converted transitions. The resolution of the Ge(Li) detector for this experiment was 2.6 keV FWHM at 1332 keV, while the electron detector exhibited a resolution of 2.5 keV FWHM at 350 keV. As an example of the quality of the coincidence data obtained, the intensity of the L-51.0 keV ce^- gated 237 keV γ-ray is 1050 counts above background, and even at 2031 keV, the peak is 85 counts above a background of only 5 counts.

The decay scheme built from these data, as it exists to date, is shown in Figs. 3, 4, and 5. We have already resolved many of the discrepancies between the decay schemes of M. Grimm[2] and A. B. Braham, et al.[3] and hope to straighten out the remaining disagreements with further analysis of these data.

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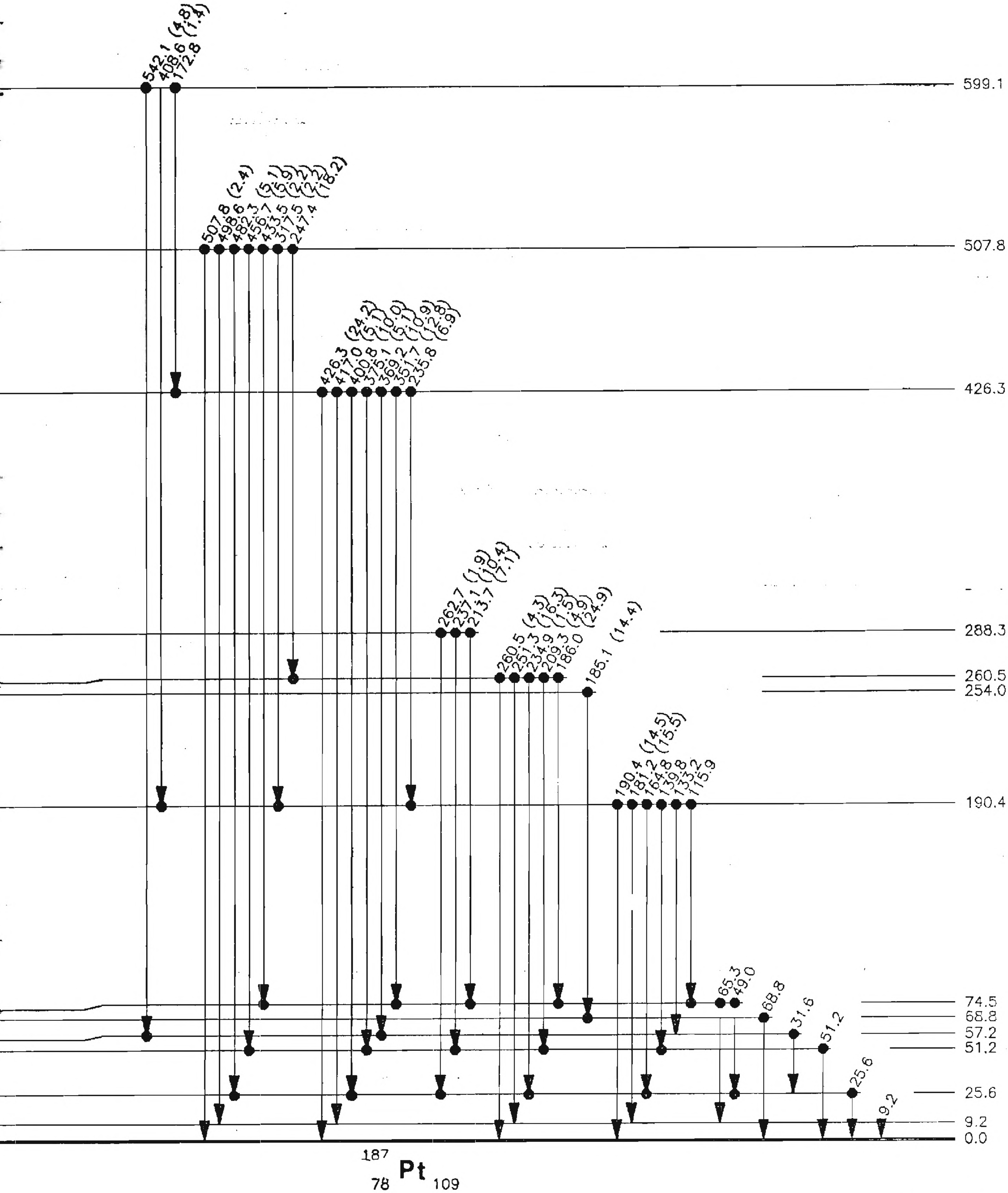
[2] M. A. Grimm, Jr., Ph.D. Thesis, Georgia Institute of Technology (1978).

[3] A. B. Braham, et al., Nucl. Phys. A332, 397 (1979).

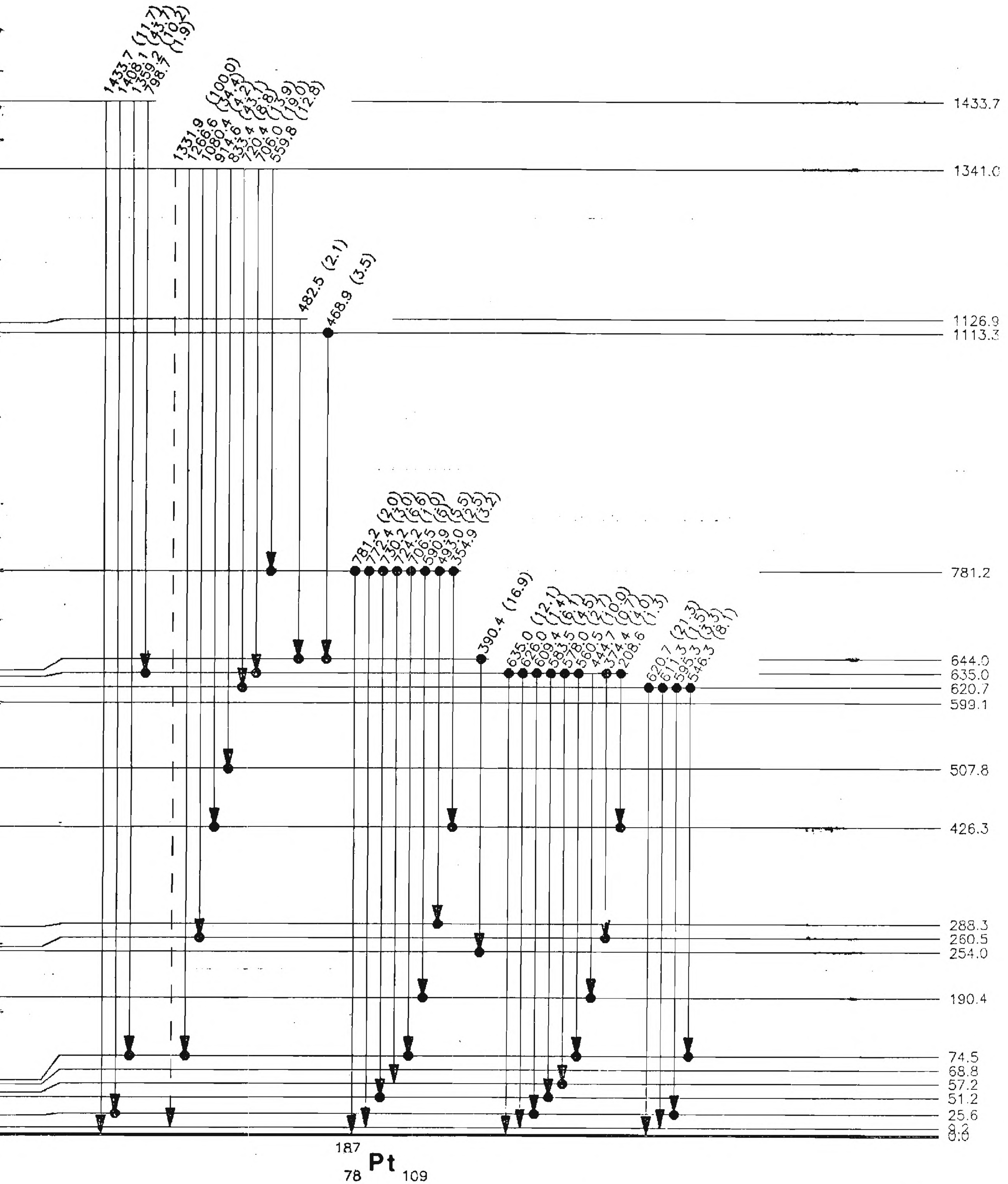
One of the main problems still to be resolved is the placement of the $i_{13/2}$ band. We know the low-spin states of the band must be populated, because of the intensity of the 117 keV γ-ray in the singles spectra. This γ-ray depopulates the band head, which is the 11/2+ member, but it is not seen in coincidence, due to the 250 μsec lifetime of this level, making the location of the band somewhat of a problem. We also need to determine the conversion coefficients for the ce^- lines, in order to assign spins and parities to the existing levels.

In addition, during the $ce^-\gamma t$ experiment of March 2, 1981, we studied the lifetime of the 120.7 keV 9/2- level in ^{187}Au. This was possible due to the fact that we produced the gold activity directly rather than from the decay of ^{187}Hg. From previous experiments the lifetime of this level was known to be about 1 sec, so we used the Multiple Time Analsis clock (MTA)



542.1 (4.8)
408.6 (1.4)
172.8
599.1
507.8 (2.4)
498.6
482.3 (5.1)
456.7 (6.9)
433.5 (2.2)
317.5 (2.2)
247.4 (18.2)
507.8
426.3 (24.2)
417.0 (5.1)
400.8 (10.0)
375.1 (5.1)
369.2 (10.9)
351.7 (12.8)
235.8 (6.9)
426.3
262.7 (1.9)
237.1 (10.4)
213.7 (7.1)
288.3
260.5 (4.3)
251.3 (16.3)
234.9 (1.5)
209.3 (4.9)
186.0 (24.9)
185.1 (14.4)
260.5
254.0
190.4 (14.5)
181.2 (15.5)
164.8
139.8
133.2
115.9
190.4
65.3
49.0
68.8
31.6
51.2
25.6
9.2
74.5
68.8
57.2
51.2
25.6
9.2
0.0
$^{187}_{78}Pt_{109}$

Fig. 3


1433.7 (11.7)
1408.1 (43.7)
1359.2 (10.2)
798.7 (1.9)
1331.9 (100.0)
1266.6 (34.4)
1080.4 (4.2)
914.6 (43.1)
833.4 (8.8)
720.4 (13.9)
706.0 (19.0)
559.8 (12.8)
482.5 (2.1)
468.9 (3.5)
390.4 (16.9)
1433.7
1341.0
1126.9
1113.3
781.2
644.0
635.0
620.7
599.1
507.8
426.3
288.3
260.5
254.0
190.4
74.5
68.8
57.2
51.2
25.6
0.0
187
78
Pt
109

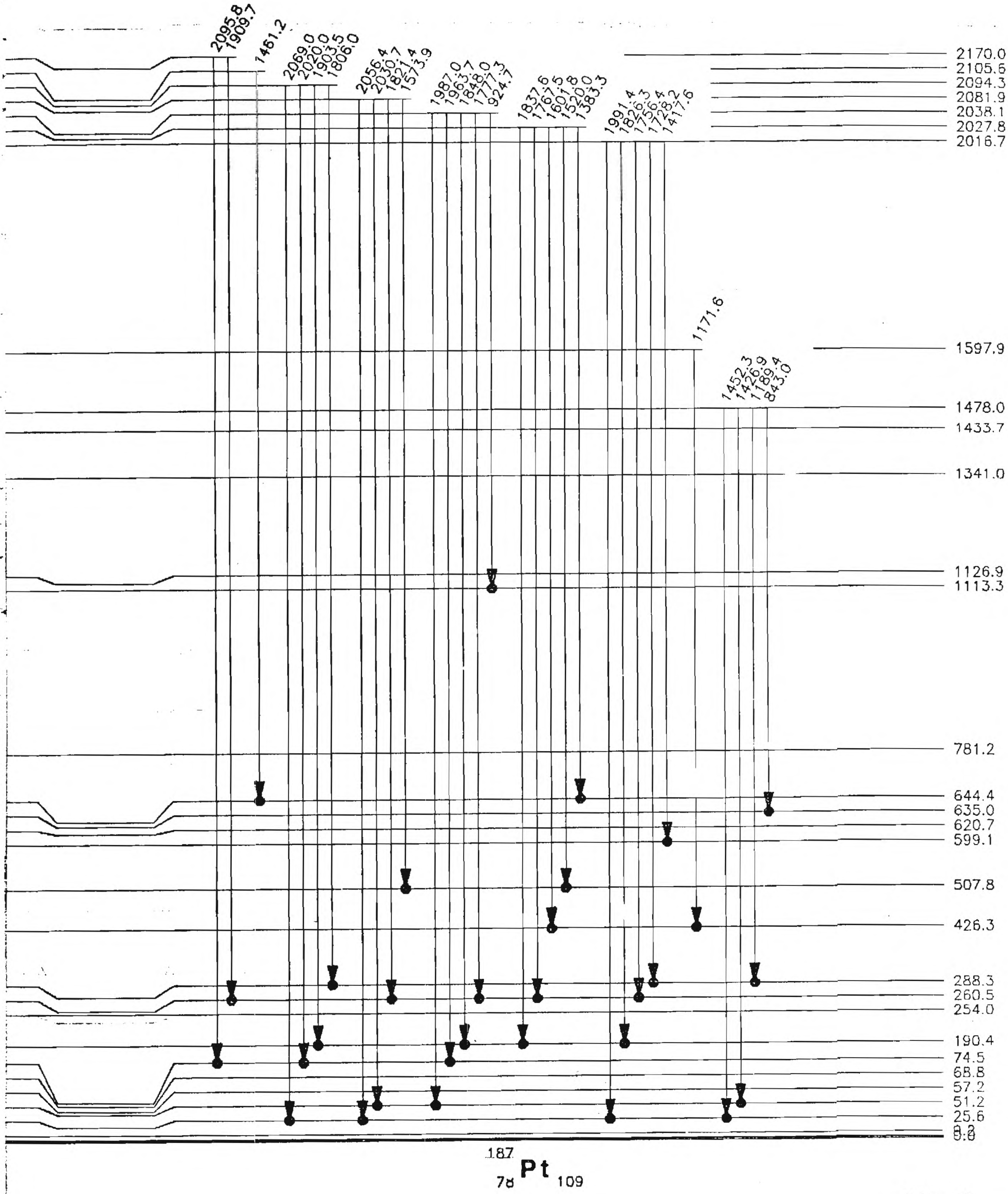

2095.8
1909.7
1461.2
2069.0
2020.0
1903.5
1806.0
2056.4
2030.7
1821.4
1573.9
1987.0
1963.7
1848.0
1777.3
924.7
1837.6
1767.5
1601.8
1520.0
1383.3
1991.4
1826.3
1756.4
1728.2
1417.6
1171.6
1452.3
1426.9
1189.4
843.0
2170.0
2105.6
2094.3
2081.9
2038.1
2027.8
2016.7
1597.9
1478.0
1433.7
1341.0
1126.9
1113.3
781.2
644.4
635.0
620.7
599.1
507.8
426.3
288.3
260.5
254.0
190.4
74.5
68.8
57.2
51.2
25.6
8.2
0.0
$^{187}_{78}$Pt$_{109}$

Fig. 5

developed at UNISOR[4]. The MTA clock was used in the multiscaling mode, in which each event is time-labelled and stored event-by-event on magnetic

4 H. K. Carter, R. A. Braga, et al., Nucl. Instr. Meth. 139, 349 (1976).

tape. We measured the lifetime of the level by following the decay of the L and M conversion electron peaks of the 101.2 keV E3 transition from the 120.7 keV 9/2- level to the 19.5 keV 3/2+ level in ^{187}Au. The decay curve obtained from these data is shown in Fig. 6, and the resulting halflife of the ^{187m}Au isomer thus is found to be 2.3 $\pm$ 0.1 sec. The study of the decay of ^{187m,g}Au $\rightarrow$ ^{187}Pt is part of the Ph.D. thesis research of Mr. Bruce Gnade.

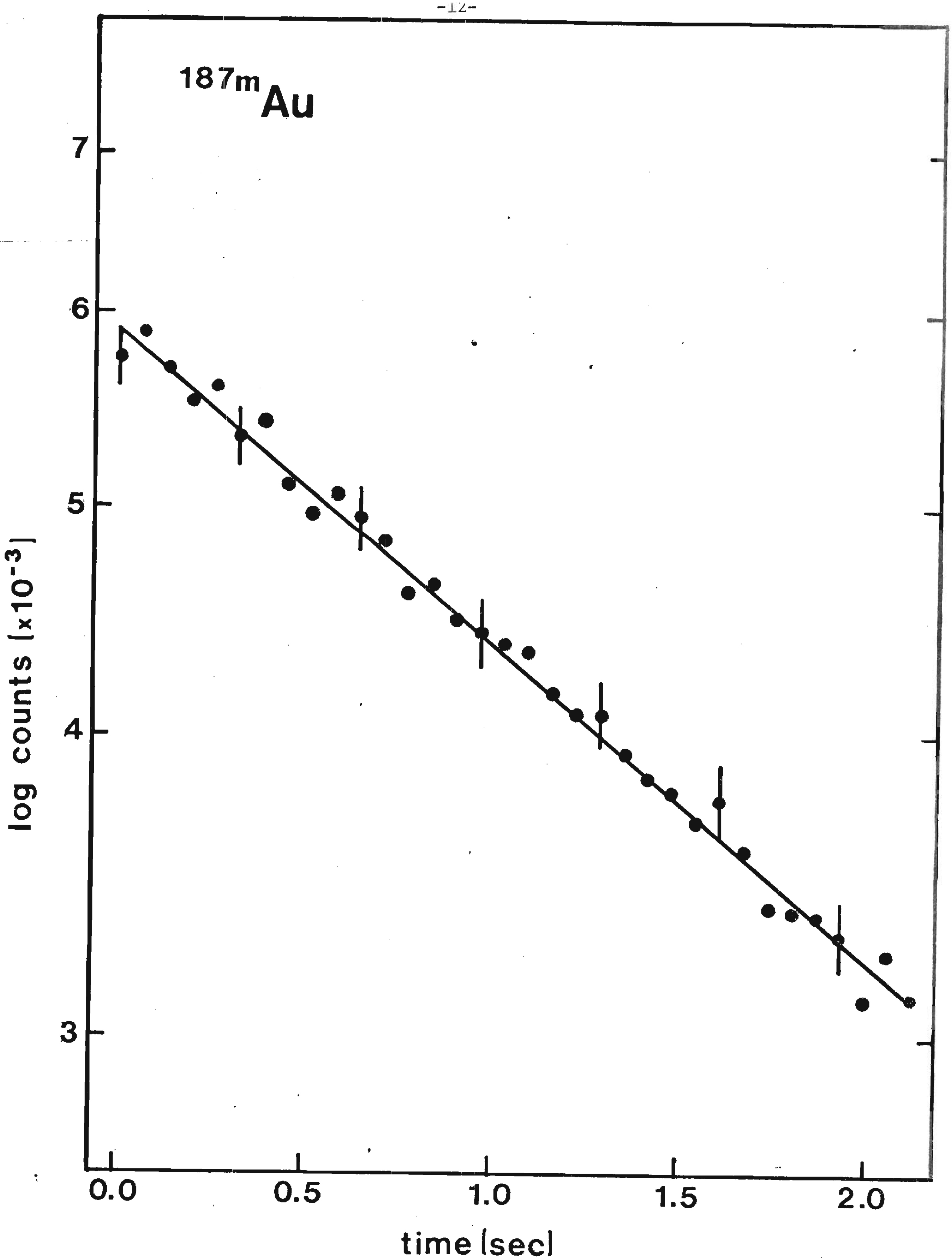
(B. Gnade, R. A. Braga, and R. W. Fink)

2.3 Decay of ^{203}At

The study of the decay of 7.4 min ^{203}At to ^{203}Po is underway following a successful UNISOR experiment performed late in October, 1980. The activities were produced via the reaction ^{nat}Ir(^{16}O,xn)^{203}At at a bombardment energy of 125 MeV and were easily extracted from the high-temperature ion source. Gamma-ray multispectral scaling and $\gamma\gamma t$ coincidence data were taken. Preliminary analysis indicates that approximately 3.5 x 10^6 $\gamma\gamma t$ events were obtained, making these data of the highest statistical quality yet achieved at UNISOR. This work is part of an on-going UNISOR effort to investigate the systematics of light nuclei near the Z = 82 closed shell and will form part of the Ph.D. thesis research of Mr. Paul Semmes.

2.4 Decay of 1.5 min ^{201}At

In continuing our UNISOR study of the A = 201 isobars, the decay of ^{201}At (1.5 min) was initiated last year as part of an effort to obtain information on the excited states of Po isotopes. These comprise part of a region which forms a completely new family of transitional nuclei and



^{187m}Au
log counts [x10^{-3}]
7
6
5
4
3
0.0
0.5
1.0
1.5
2.0
time [sec]

provide tests for models and concepts that have been developed to describe nuclei with $Z \leqslant 80$.

The At activity was produced in the $^{nat}Ir(^{16}O,5\text{-}7n)^{201}At$ reactions and the data collected to date (consisting of γ-ray multiscaling) have been analyzed. The halflives obtained from these data fall into three categories (as shown in Fig. 7): (1) $T_{1/2} \simeq 1.6$ min, i.e., the 493 keV γ-ray; (2) $T_{1/2} \simeq 2.5$ min, i.e., the 630 keV γ-ray; and (3) a growth-decay with a 1.6 min parent activity, i.e., the 854 keV γ-ray. The results are given in Table 1 below.

Table 1 - Gamma-rays classified by halflife in the A = 201 decay chain.

	$T_{1/2} \simeq 1.6$ min	$T_{1/2} \simeq 2.5$ min	Decay $T_{1/2}$		
E_γ(keV)	493	630	85	9 min	^{197}Pb
	592	436	240	15 min	^{201}Bi
	583	537	418	9 min	^{201}Po
	761	1005	854	9 min	
	722		867	9 min	

The identification of the 85 keV γ-ray as belonging to ^{197}Pb, the 240 keV line to ^{201}Bi, and the 418 keV line to the 13/2+ isomer in ^{201}Po demonstrates the complications that arise due to the competing β^+-EC and α-decay of ^{201}At and the fact that both ^{197}Bi and ^{201}Po exhibit a 9 min halflife. X-ray-γ-t coincidence data, therefore, become a necessity in order to make Z assignments. To this end such measurements are planned in conjunction with the on-going study of ^{203}At decay.

(R. A. Braga)

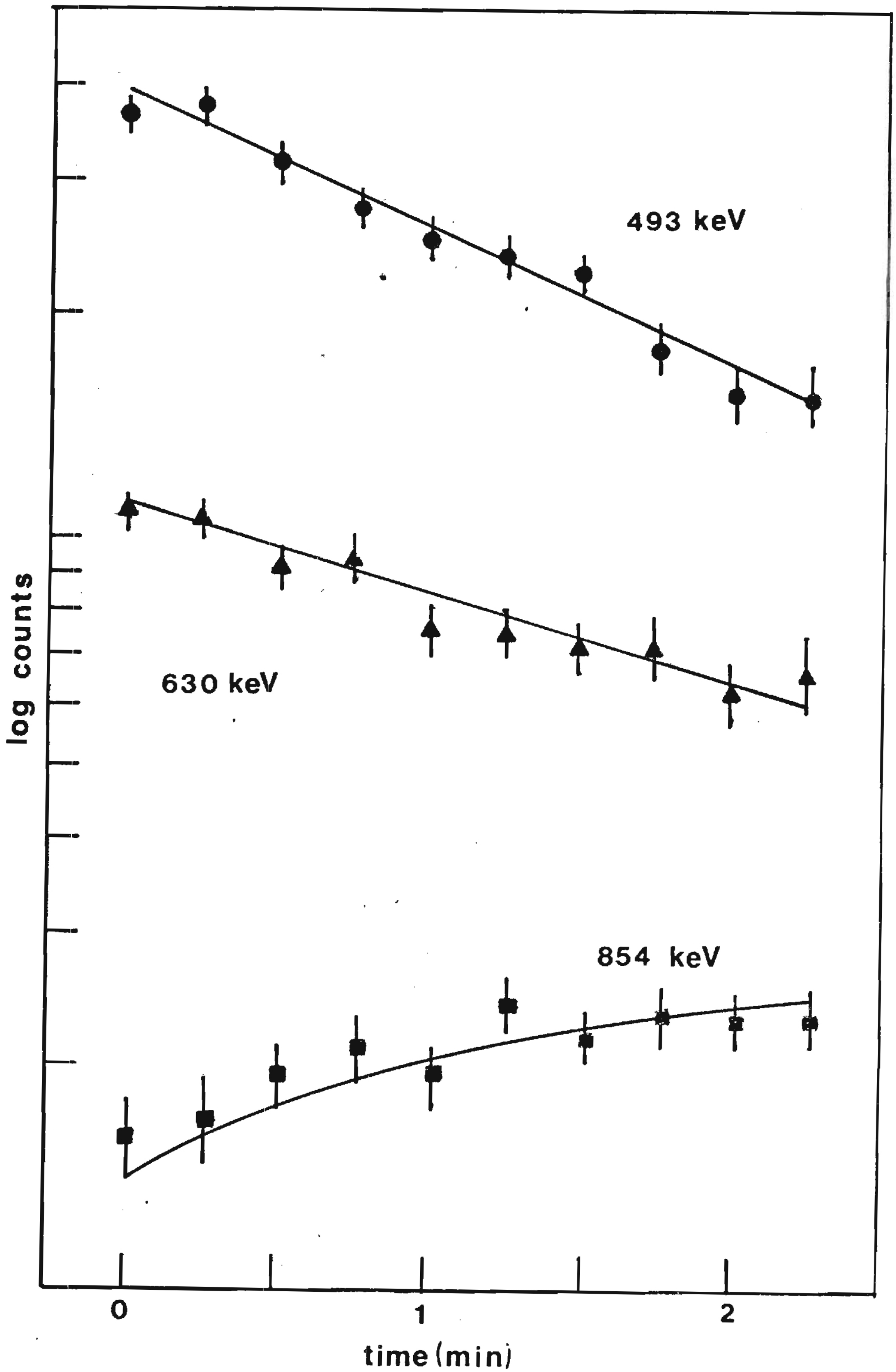


Fig. 7

2.5 Decay of 3.5 min ^{125}Ba

In late April, 1981, the initial UNISOR run on the study of the decay of ^{125}Ba was performed. The Ba activity was prepared by the bombardment of natural Ag foils with 125 MeV $^{20}Ne^{+5}$ beam. The high-temperature ion source was used with the injection of CF_4 gas to enhance Ba extraction (as BaF^+ ions) while retarding Cs^+ extraction (since CsF is non-volatile).

Limited $\gamma\gamma t$, γXt, as well as γ-ray multispectral data were obtained. Preliminary analysis has identified several γ-ray lines associated with 3.5 min ^{125}Ba decay (Table 2); however, no activity associated with the 8 min ^{125m}Ba decay was observed. The present results are in agreement with the limited decay scheme for levels in ^{125}Cs of Arlt, et al.[5]. Additional runs are planned. (R. A. Braga)

[5] R. Arlt, A. Jasinski, W. Neubert, and H. G. Ortlepp, Acta Phys. Pol. (Warsaw) B6, 433 (1975).

Table 2 - Gamma-rays from the decay of 3.5 min ^{125}Ba.

E_γ (keV)	55.0	63.1	77.6	85.4	108.0	140.9
	and Cs K x rays					

2.6 Lifetimes of the $g_{7/2}$ Shell-Model Intruder States in ^{109}Ag

The $g_{7/2}$ shell-model state is known to intrude across the Z = 50 shell closure[6] to appear in the odd-mass In isotopes as a deformed rotational band structure, coexisting with spherical hole states. Evidence

[6] W. Dietrich, A. Backlin, C. O. Lannergard, and I. Ragnarsson, Nucl. Phys. A253, 424 (1975).

that the $g_{7/2}$ intruder band lies close to the Fermi energy in $^{109,111}Ag$ has already been recognized[7,8].

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[7] R. L. Auble, F. E. Bertrand, Y. A. Ellis, and D. J. Horen, Phys. Rev. C8 2308 (1973).

[8] M. D. Glascock, E. W. Schneider, W. B. Walters, and R. A. Meyer, Z. Physik A283, 415 (1977).

A study of the $g_{7/2}$ shell-model intruder state in ^{109}Ag has resulted in the determination of the half-life for the 3/2+ (724.4 keV) band member populated in the decay of 13.43 hour ^{109}Pd, sources of which were prepared in the Georgia Tech Research Reactor by the enriched $^{108}Pd(n,\gamma)$ reaction. The level lifetime measurements were performed utilizing delayed coincidence techniques employing state-of-the-art ARC (amplitude and risetime compensated) timing. Data acquisition consisted of multiparameter $\gamma\gamma t$ coincidence data taken with a Ge(Li)—Ge(HP) detector system, as well as with a Ge(Li)—plastic scintillator (NE-111) system.

A centroid shift technique employing a first-moment analysis[9] was used to evaluate the time-to-amplitude (TAC) spectrum from the Ge(Li)—Ge(HP) system, while a deconvolution procedure utilizing a linear regression analysis[10] was used on the Ge(Li)—plastic scintillator TAC spectrum.

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[9] M. Birk, G. Goldring, and Y. Wolfram, Phys. Rev. 116, 730 (1959).

[10] B. A. Alikov, M. Budzynski, R. Ion-Mikhai, and V. A. Morogov, Sov. J. Part. Nucl. 7, No. 2, 164 (1976).

The resulting halflives, utilizing the two different coincidence systems and employing different analysis procedures, are in excellent agreement yielding an average value of 3.2 ± 0.8 nanosec for the 3/2+ (724.4 keV) level in ^{109}Ag. No measureable halflife for the 706.9 keV level, tentatively assigned as being the 1/2+ member of the $g_{7/2}$ band, was obtained. The systematics of the $g_{7/2}$ shell-model intruder band in ^{109,111}Ag are shown in Fig. 8 and a summary of the properties of the γ-rays depopulating the 724.4 keV level in ^{109}Ag is given in Table. 3. (R. A. Braga and R. W. Fink)

Table 3 - Properties of Gamma Transitions Depopulating the 724.4 keV level in ^{109}Ag.

E_γ (keV)	309.1	413.0	636.3	724.4
$J\pi$	5/2-	3/2-	7/2+	1/2-
Multipolarity	E1	E1	E2	E1
Gamma branching	0.22	0.32	0.46	0.004
Partial $T_{1/2}$	14.5 nsec	10.0 nsec	6.9 nsec	800 nsec

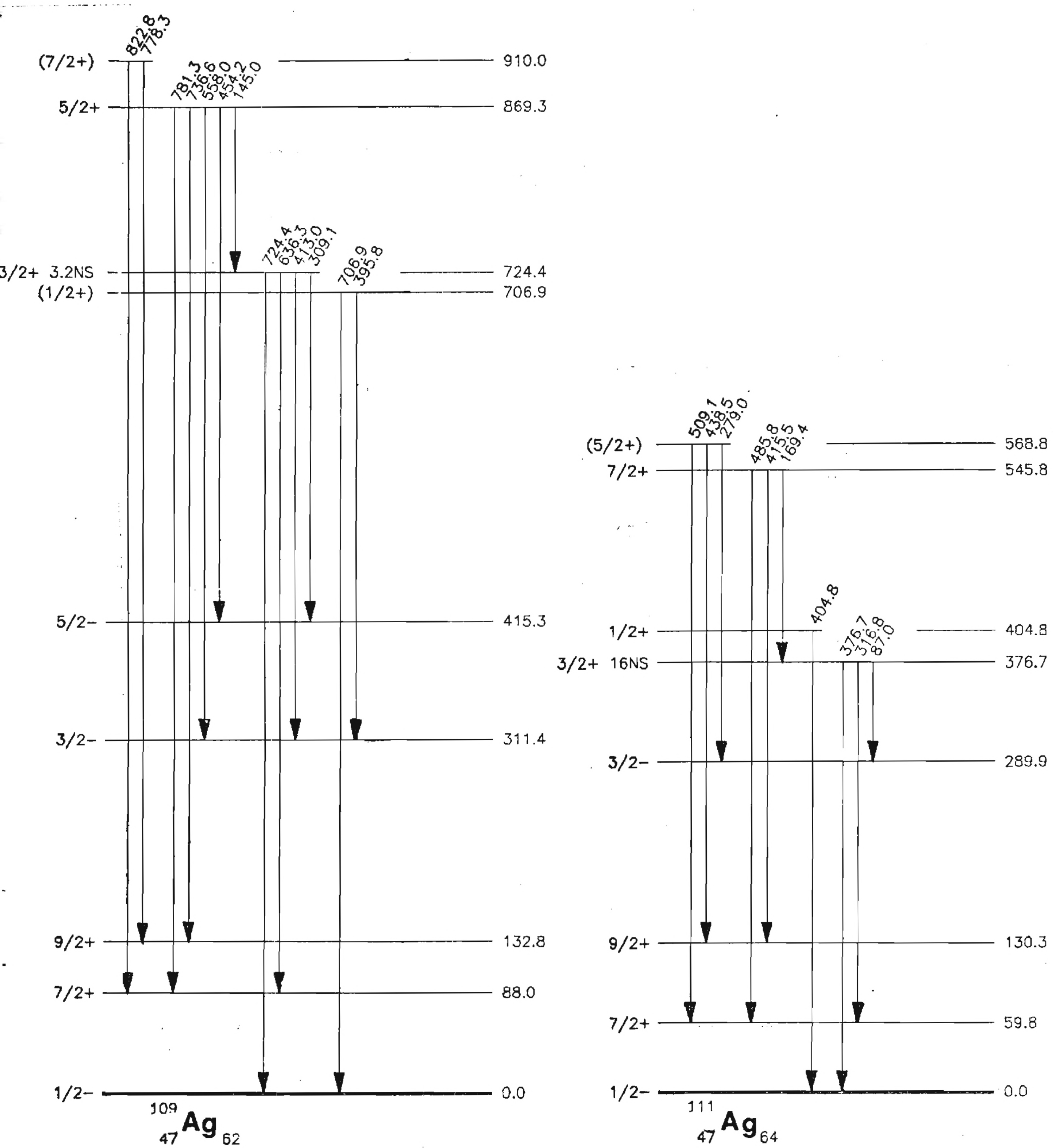
2.7 Orbital Electron Capture Probability and Decay Energy in ^{207}Bi Decay.

The radionuclide, 33.4 year ^{207}Bi, is an important calibration standard for both low- and high-energy photons and for high-energy electrons. However, the mass difference ^{207}Bi-^{207}Pb, (Q_{EC} = 62.4 keV) given in the 1977 mass tables[11)] is based on only one measurement of the total L/K orbital electron capture ratio performed in 1964 with a proportional counter method[12)].

11 A. H. Wapstra and K. Bos, Atomic Data-Nuclear Data Tables 19, No. 3, 177 (1977).

12 A. deBeer, H. P. Blok, and J. Blok, Physica 30, 1938 (1964).

In the course of other x-ray coincidence measurements on ^{207}Bi sources, we have developed a new method by which L_1 subshell vacancies can be signaled


(7/2+)
910.0
822.8
778.3
5/2+
869.3
781.3
736.6
558.0
454.2
145.0
3/2+ 3.2NS
724.4
(1/2+)
706.9
724.4
636.3
413.0
309.1
706.9
395.8
5/2-
415.3
3/2-
311.4
9/2+
132.8
7/2+
88.0
1/2-
0.0
109
47
Ag
62
(5/2+)
568.8
509.1
438.5
279.0
7/2+
545.8
485.8
415.5
169.4
1/2+
404.8
404.8
3/2+ 16NS
376.7
376.7
316.8
87.0
3/2-
289.9
9/2+
130.3
7/2+
59.8
1/2-
0.0
111
47
Ag
64

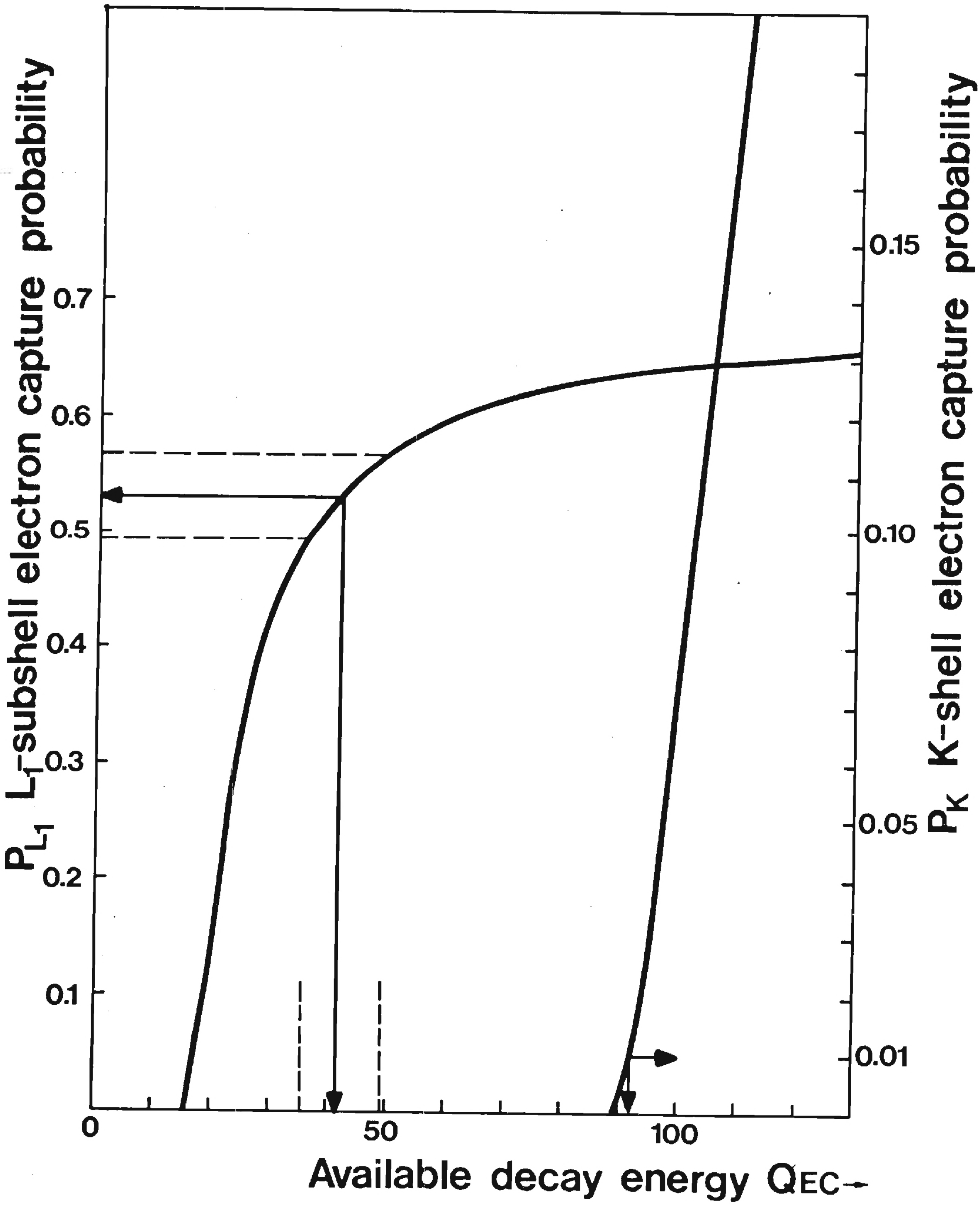
in a coincidence spectrum by the presence of L_1 subshell characteristic x rays in the L_γ x-ray peak. Thus, we carried out measurements of the L x-ray spectrum gated by 1770.23 keV γ-rays from the 2339.89 keV excited state in ^{207}Pb. These measurements were performed with a 5% Ge(Li) γ-ray detector (resolution = 230 eV FWHM at 14.4 keV) operated in a γγt coincidence mode with the Nuclear Data 4420 Multiparameter analyzer. By analysis of the L_γ x-ray peak in coincidence with this γ-ray gate, we obtain a value of the L_1 subshell orbital electron capture probability $P_{L_1} = 0.531 \pm 0.037$ (2σ) from which a new determination of the ^{207}Bi-^{207}Pb mass difference $Q_{EC} = 42^{+8}_{-5}$ keV to the 2339.89 keV level is obtained, as shown in Fig. 9. This also demonstrates that K-capture is definitely absent to this level. From analysis of the difference between the total L-capture probability P_L and the value of P_{L_1}, the ratio $P_{L_2}/P_{L_1} = 0.09$ is obtained, assuming from the fact that this transition is an allowed one that $P_{L_3} = 0$. These results will be submitted for publication in Nuclear Physics.

(M. Tan, P. V. Rao, R. A. Braga, and R. W. Fink)

3.0 Investigations of the Interacting Boson-Fermion Approximation.

We are continuing our systematic comparison of the Interacting Boson-Fermion Approximation model predictions with current experimental data on nuclei of interest to UNISOR. In addition to the computer codes "PHINT" and "ODDA" written in the IBA-1 description, the code "NPBOS" written in the IBA-2 description, which distinguishes between proton and neutron bosons, is now operational on the Georgia Tech CDC Cyber 70/74 computer.

(R. A. Braga)



P_{L_1} L_1-subshell electron capture probability
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.15
0.10
0.05
0.01
P_K K-shell electron capture probability
0
50
100
Available decay energy Q_{EC}

Fig. 9

4.0 Miscellaneous technical topics

4.1 Codes and Operations with the CDC Cyber 70/74 Computer

The imposition this past year of a full-rate cost charge schedule for use of the Georgia Tech CDC Cyber 70/74 computer has necessitated economy in processing nuclear spectroscopic data. To this purpose, we have developed a battery of codes that fall into three categories: (1) data manipulation; (2) spectral analysis; and (3) display codes.

The data manipulation codes (all written at Georgia Tech) perform such tasks as pre-analysis of $\gamma\gamma t$ coincidence data resulting in more than a 10-fold reduction in the bulk magnetic tape storage requirement by means of a bit reduction and packing procedure (PRESCN)[a], pulling of up to 100 simultaneous energy gates utilizing pointer array logic (GATESCN)[a], along with providing a listing of coincidence gate output spectra (GATELST).

The spectral analysis codes include procedures that identify peaks of interest (PKFIND), determine peak intensities by the fitting of a skewed Gaussian shape (SKEWGS)[b], determine halflives by a linear regression technique (FRANTIC)[c], as well as several other codes that calculate internal conversion coefficients, multipole mixing ratios, peak centroids, etc.

The display codes permit the plotting of hisogram type energy spectra (HISTO) and energy level schemes (LVLSCM), as seen in this report. In addition, a code CHNSPC now permits the writing of all output spectra in IBM coded format for further processing off-campus.

(R. A. Braga and B. E. Gnade)

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[a] Nuclear and X-ray Spectroscopy with Radioactive Sources, ORO-3346-214, 26 (1977).

[b] Ames-ERDA Lab - Program SKEWGAUS.

[c] MIT Tech. Rept. No. 76 (1962).

4.2 Techniques in the Analysis of Data

As mentioned in Sect. 2.2, in the $^{187}Au \rightarrow {}^{187}Pt$ $\gamma\gamma t$ experiment of August, 1980, we used an ORTEC Gamma-X detector for improved resolution at low energies. Even with a resolution of 850 eV at 110 keV, we still have many peaks that are unresolved and some doublets that appear to be single lines. Many times the only way to determine that there is more than one γ-ray in a peak is to look at the coincidence data to see if the γ-ray of interest shows up in more than one place in the decay scheme. When multiplets are suspected, we use a technique which we call "running gates." In this method a narrow gate, approximately the FWHM of the peak, is advanced one channel at a time across the peak. By observing how the intensities of peaks in the coincidence spectrum vary as the gate moves, the number of components in the multiplet and their intensities can be determined. As an example, the 185 keV peak "running gate" is shown in Fig. 10. It can be seen from the figure that the lines in coincidence have a maximum intensity in three different gates, indicating that three components exist in the peak. It shows that 390.4, 602.0, and 295.2 keV lines are in coincidence with the 185.1 keV peak; and that the 201.9 keV line is in coincidence with the 186.7 keV peak. This technique is extremely useful in analyzing unresolved multiplets. The three components in the peak lie at energies of 185.1, 185.7, and 186.7 keV, based on the results from Fig. 10. (B. E. Gnade)

4.3 Equipment added during 1981

This year we purchased a Canberra Model 2020 spectroscopy amplifier. This NIM module is capable of handling counting rates of as much as 100K/sec with no effect on resoltuion.

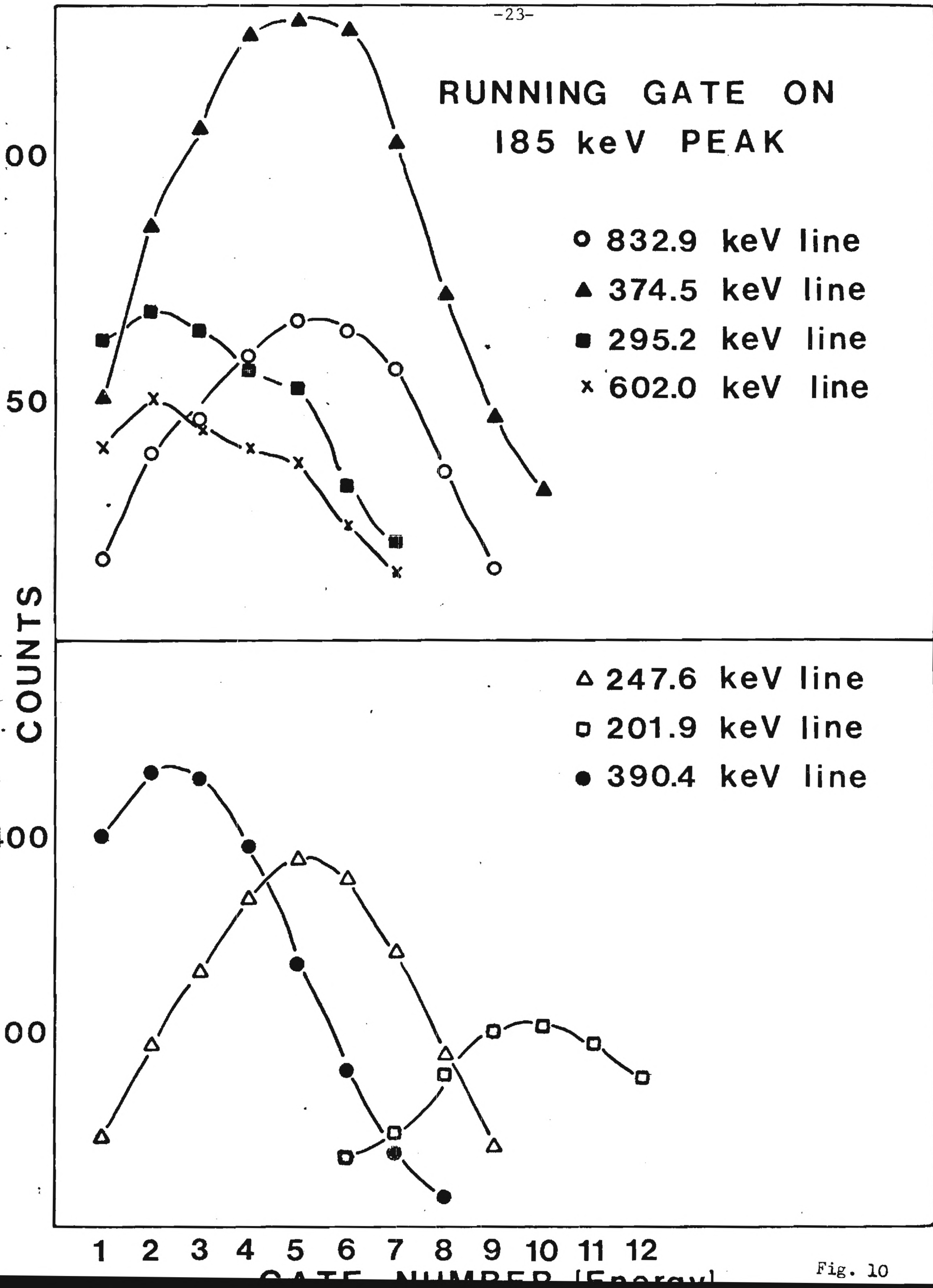
RUNNING GATE ON
185 keV PEAK
832.9 keV line
374.5 keV line
295.2 keV line
602.0 keV line
247.6 keV line
201.9 keV line
390.4 keV line
COUNTS
00
50
00
00
1 2 3 4 5 6 7 8 9 10 11 12

Fig. 10

Our Chemistry Electronics Shop designed and built a 4-fold coincidence logic module for use with the laser spectroscopy facility at UNISOR. In addition our Chemistry Machine Shop fabricated several detector port cups out of high-Z-free aluminum for use with low-energy photon measurements at UNISOR. A battery-operated GM counter survey chirper was purchased for the radiochemistry laboratory.

5.0 Personnel

Senior Staff

Dr. R. W. Fink, Professor of Chemistry & Principal Investigator (1/4 time, 12 months).

Dr. R. A. Braga, Research Associate (full-time DOE Feb. 1 - Aug. 31, 1981; 50% DOE - 50% teaching after September 1, 1981).

Graduate Students

Mr. Bruce E. Gnade (Chemistry). Completing Ph.D. thesis research. (1/2 time DOE Feb. 1 - Aug. 31, 1981; supported by teaching assistantship after September 1, 1981).

Mr. Paul B. Semmes (Chemistry). Beginning Ph.D. thesis research. (1/2 time DOE Feb. 1 - Aug. 31, 1981; NSF fellow 1981; supported by teaching assistantship after September 1, 1981).

Mr. Gary P. Schwaiger (Chemistry). Beginning graduate studies for Ph.D. in nuclear chemistry September 1, 1981, supported by teaching assistantship.

6.0 List of Publications and Papers Presented at Meetings.

1) "A Remote Device for De-Encapsulating Reactor-Irradiated Samples," G. P. Schwaiger and R. W. Fink, Nucl. Instr. Meth. (in press, 1981). [ORO-3346-243]

2) "Decays of $^{117}Xe \rightarrow {}^{117}I \rightarrow {}^{117}Te$," R. S. Lee, W. D. Schmidt-Ott, A. C. Xenoulis, R. W. Fink, and other UNISOR coauthors, Phys. Rev. (to be submitted, 1981).

3) "Studies of Z = 81 Transitional Nuclei, I. ^{197}Pb Decay," L. L. Collins, L. L. Riedinger, G. D. O'Kelley, C. R. Bingham, M. S. Rapaport, J. L. Wood, and R. W. Fink, Phys. Rev. C (submitted, 1981).

4) "Studies of Z - 81 Transitional Nuclei. II. ^{193}Pb and ^{195}Pb Decay," L. L. Collins, L. L. Riedinger, G. D. O'Kelley, J. L. Wood, and R. W. Fink, Phys. Rev. (to be submitted, 1981).

5) "Very Slow M4 Transitions and Shell-Model Intruder States in $^{199,201}Bi$," R. A. Braga, W. R. Western, J. L. Wood, R. W. Fink, and other UNISOR coauthors, Nucl. Phys. A349, 61 (1980).

6) "Excited States in $^{189,190}Pt$ from the decays of $^{189m,190g}Au$," B. E. Gnade, J. L. Wood, and R. W. Fink, Bull. Am. Phys. Soc. 25, 740 (1980).

7) "Studies of Radioactive nuclei far from Stability with Heavy Ion Beams and On-Line Mass Separation," R. W. Fink, Bull. Georgia Academy of Science, p. 63 (Atlanta, Georgia, April 25, 1981).

8) "Experimental Methods in Nuclear Chemistry: Decay Studies of ^{201}Po and ^{203}At," Paul B. Semmes, Bull. Georgia Acad. Sci. p. 63 (Atlanta, Georgia, April 25, 1981).

9) "M4 Isomerism and the Observation of the $s_{1/2}$ Shell-Model Intruder State in ^{201}Bi," Robert A. Braga, Bull. Georgia Acad. Sci. p. 62 (Atlanta, Georgia, April 25, 1981).

10) "Excited States in ^{187}Pt from the Decay of ^{187}Au," Bruce Gnade, Bull. Georgia Acad. Sci. p 63 (Atlanta, Georgia, April 25, 1981).

11) "Excited States in ^{187}Pt from the Decay of ^{187}Au," B. Gnade and R. W. Fink, Bull. Am. Phys. Soc. (Nov. 1981, Asilomar, Calif.) (in press).

12) "Lifetime of the 120.7 keV Isomer in ^{187}Au by Multiple Time Analysis," R. A. Braga and R. W. Fink, Bull. Am. Phys. Soc. (Nov. 1981, Asilomar, Calif) (in press).